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A Holistic Approach towards Optimizing Guidlines and Criteria For Sustainable Dwellings

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Abstract

This masters' research is a stepping stone towards a comprehensive assessment and guidance system that would is to be further developed in a post-masters stage. It starts by performing a critical analysis to BREEAM's Code for Sustainable Homes (CfSH), describing the various sections and requirements to satisfy a code six rating. To pursue the goal of comprehensive guidelines, the research will pursue literature pertaining to Living Building Challenge (LBC), PassivHaus and BREEAM, each chapter concluding with a critical analysis of the system, its stronger points and its potential for implementation in the final framework. A cross case analysis between three case studies reflecting on each of the systems will be performed, analyzing the steps taken and the final output of each system's efforts on a building that achieved its highest qualification. This will include EcoSense house and zHome for LBC, Kingspan Lighthouse for BREEAM CfSH and Lancaster CoHousing project for PassivHaus.

The research progresses through its chapters by critically analyzing and extrapolating criteria, concluding them at the end of each chapter in order to be analyzed under the larger umbrella of categories. Right before the thesis concludes, the culmination of criteria extracted through the previous chapters were organized and assigned to their respective categories. And finally, based on the overall qualitative and quantitative results of this study, the researched prepared a set of guidelines encompassing a preliminary step towards creating an assessment system with further post-masters research.

Keywords: Living Building Challenge, BREEAM, PassivHaus, Holistic, Sustainable, criteria, categories, framework, case study, communal.

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Chapter 1: Introduction to the general issue

Climate change has been a lingering issue since the mid-19th Century, undeniable empirical evidence has been extracted through the years confirming a number of concerns and their effect both within their local contexts and globally (Walther *et al.*, 2002, pp. 389–395, Wise *et al.*, 2014, pp. 325–336) . A number of markers used to calculate the pace of climate change are identified including but not limited to the elements presented in table 1 (Global Change, 2014)

Table 1. Climate Change Markers Identified by the US global change website.

CO2 Concentration	Temperature Change	Heavy Precipitation
Precipitation Changes	Sea level rise	Extreme Weather

Globally, a steady increase leading to a differential temperature of 0.8 ^{0}C between 1880 and 2012 is empirically proven, the mentioned increase is paired with a rapid increase in CO2 concentration in the atmosphere averaging a differential of 105 ppm. (Global Change, 2014)

United Nations Environmental Programme (UNEP) estimates an average urban environment contributes to around 75% of greenhouse gases (UNEP, 2014). While statistics in the UK average consumption based services such as shown in table 2 (Department of Energy, 2014, p. 12):

Table 2 Percentages of energy consumption in the UK per sector

Residential Structures : 17%	Businesses: 16.25%	Transport: 25%
Waste Management 2.2%	**Public Sector: 0.4%**	

These services contribute to an average of 61% excluding energy production. The energy production sector alone adds another 38% to this calculation, 83% of the latter is generated through coal powered plants, the mainstream energy generation method in the UK (Department of Energy, 2014, p. 12), which contributes 0.527 kg CO_2/kWh (DEFRA, 2008) or 0.529 kg CO^{2e} /kWh with sequestration (BRE and Pout,2011)

Deduced by the United Kingdom's Government Department for Environment, Food and Rural Affairs (DEFRA) calculations within the UK, a large portion, accounting to 59% (*DEFRA*, 2015) of CO2 emissions are accounted to frequently used buildings and transport. An amount of up to 140mTon CO2 (*DEFRA*, 2015) is contributed by the housing sector alone in the UK, distributed between amenities such as lighting, electronic and electric devices and heating, in addition to gas in case of use of gas boilers or stoves.

The number of houses in the UK increases at a steady rate of 1% per year. At 180,000-190,000 dwellings per year, totaling at 26 million dwellings; as of 2011 census (Department of Energy and Climate

Change, 2012). Granted the business addition of 21,087 Hectares, 18% of which contribute to office spaces, there is a large potential for generation and contribution to resilience within the business sectors. (VOA, 2012)

Efforts going into micro-generation have proved useful but the scale and the policy implemented by governments have not proved enough to cause significant impact and reduction. Some policies implemented in Germany under the PassivHaus (Mead and Brylewski, 2011) scheme have proved successful, providing up to 260.67 mW through the 100,000 Roof initiatives. This has led to a reduction of 0.014 Ton CO2 per 1€ spent, or 1 Ton per 71€, a total of 70-80% reduction in heating energy and 50-70% reduction in overall energy use (Kwok and Grondzik, 2011) compared to a 20% energy reduction targeted for 2030 by the Building Research Establishment Environmental Assessment Methodology (BREEAM) (Hamilton *et al.*, 2014, pp. 255–275). On the other hand comparison between both systems needs more research to reflect on their efficiency, given that both Germany and England have a Cfb climate zone (*World Maps of Köppen-Geiger climate classification*, 2010, Kottek *et al.*, 2006, pp. 259–263), with typically similar temperature patterns with a range of seasonal changes that can topple the balance.

Energy by itself or electricity as formerly explained is not the only high consumption variable in this equation. Heating, cooling, ventilation day-time space lighting, food and preparation are all sources of energy consumption that need to be tackled in a more direct and detailed manner.

In addition, water and energy resources for mass-food production, specifically edible flora, can be marginally reduced by an array of smaller projects that assist their direct surrounding by at least the minimal requirement (Lipton, 2006, pp. 58–85).

By considering the facts mentioned, it's essential to have a holistic understanding of all the energy, water, and emissions outlets within a dwelling to be able to fully tackle emissions problems. A building's operational phase contributes to 80% of the building's complete Life Cycle Analysis (UNEP, 2009), while a majority of emissions during operation in Cfb climate zones are contributed to heating & cooling loads, other sundries and day-to-day activities remain not tackled and demand further research to achieve true sustainability and efficient global climate change agendas.

By introducing an essential aspect of micro-horticulture within each plot, each structure, residential, business or public will input to itself or the larger grid, by creating a large number of micro-generation plots a larger output can be generated that would contribute to at least a portion of requirement in addition to reduction of Carbon Dioxide emissions by reducing what is labelled as food miles, the distance between food's source to the market and eventually the mouth it feeds (La Trobe, 2001, pp. 181–192). An issue that is briefly tackled within the International Living Building Institute's (ILBI) Living Building Challenge (LBC) documentation requirements in the Place petal; the category equivalent that pertains to the site and surroundings of a building in the LBC, given a set of equations that consider the Floor Area Ratio (ILBI, 2013), it however does not reflect on the number of users and their feeding requirements and thus further research to refine or amend that policy must be performed.

1.1 Project Context and Current state

This project is being conducted during the state in which the United Kingdom's building regulations adopt a BREEAM CfSH code three minimum requirement for all new constructions and renovations, , which is rumoured to be ascended to the equivalent code 4 as learnt by discussions with BRE personnel at the BRE stall during Eco-Build 2015 during question and answer session following the announcement of the Home Quality Mark for the first time. While that code will be embedded within building regulations and design standardization, it will however be given a new face; BREEAM's Code for Sustainable Homes will be accommodated under the title of "Home Quality Mark", announced in March 2015 during EcoBuild by the BRE staff and on both a dedicated website and the CfSH page, to be fully released in October 2015 as public friendly approach for non-professional home buyers and investors, to facilitate the understanding of sustainable home design quality rating in the form of a simple five star system. Whilst the Home Quality Mark –HQM- hoists a number of technical and sustainable values from CfSH, it also adopts a number of values that were not present before, some of which are similar to the imperatives of the Living Building Challenge –LBC- and will be described and compared in later chapters. Which to add, is currently not used within the UK, there are currently only 6 fully accredited living buildings in the world, and a number of Zero Energy buildings under the same scheme.

Furthermore, PassivHaus (Passive House), is increasingly being used in the UK, under supervision, training and development of both PassivHaus Institute of the UK (PHI) (PassiveHaus Institute, 2015), and BRE PassivHaus sponsored and supported by the BRE (BRE and PassivHaus, 2011). While being a used as a method of reducing energy consumption of buildings passively, it also maintains a more strict requirement for unregulated energy limit, which to maintain under future Carbon reduction protocols, would require active low or zero carbon measures and on site supply to reach the PassivHaus limit, which strongly supports energy efficiency and passive design solutions rather than active systems (PassivHaus, 2011).

In addition to the design standards' section of this thesis, and the matter of regulating and promoting efficiency in buildings along with the issue of providing produce at home, there are currently no laws or regulations abiding home owners with metering their electric use –except for billing purposes- nor ones requiring the availability of an on-site food source. The options surrounding these measures will be further tackled in this thesis project.

In order to unify terms within this thesis project, the term **Component** will be used to refer to the different categories within the chosen rating systems. Whilst analyzing the LBC, Component will be replaced by **Petal** to refer to its original naming.

1.2 Problem Statement

This study targets an essential building unit in every city or town's composition, the housing sector, which has the potential to detain the damage to the planet's atmosphere and potentially decelerate the seemingly unstoppable climate change (Solomon et al, 2009, Bales and Duke, 2008). A damage severe enough that the International Energy Agency (IEA) set a target to detain the long term impact to the 2 °C target over 50 years instead of the projected 3.6 °C – 5.3 °C by the IEA (IEA, 2013). This project specifically targets detached, semi-detached and attached houses within an urban context, the units which contribute 17% to the composition of buildings in the UK's cities, these buildings which are operational on a 24 hour basis, hosting individuals and families along with their collective needs for survival, entertainment and shelter, only get an average of 6 hours and 35 (The Sleep Council, 2013) minutes daily of down time during the occupants' sleep period, during which only elements such as lighting and entertainment are switched off. By targeting that sector using the proper set of strategies, a remarkable reduction in emissions can be achieved, thus at least reducing the emissions created by one of the largest sectors in the construction industry.

In addition to problems associated with performance, issues associated with resilience will be targeted including micro horticulture, share of site resources between units of a cluster and communal generation to share heating, cooling and generation loads (Coyle and Duany, 2010). The sum of all when paired with user awareness and calculated sustainable design, would be able to produce an optimized residence capable of standing non-reliant on mains grid, or if ambitious enough, independent from the grid.

In the current industry, the limits of finance and costs hinder potential builders and buyers from purchasing sustainable homes, whilst the competition between sustainable assessment tools and the potential profit from procuring a certificate from those schemes hinders comprehensive design.

The research hopes to produce a set of potential guidelines that would be the first stepping stone on a long term roadmap for comprehensive, optimum sustainable housing design achievable through balance between passive and active criteria.

1.3 Research Questions

In order to be able to begin extrapolating a set of guidelines or strategies derived from the schemes formerly mentioned –BREEAM CfSH, PassivHaus and LBC- in addition to the collective literature reviewed for this research, an organizational hierarchy must be put in place in order to study and extract the necessary information in an organized summary per standard. All of which is to be collectively assessed under two criteria:

- Potentials and constraints dictated by implementing the strengths of each scheme into a single comprehensive set of guidelines.
- Degree of Compatibility, weather the ideologies and approaches of two or more of the schemes would overlap or contradict with the other, and the ways to overcome such struggle by neglecting standard-specific restraints and focusing on the bigger holistic design picture.

These two criteria will be used to formulate the proposed set of guidelines and the proposed outcome of this research. To do so, answering the following questions will help structure the critical section of the analysis chapters and organize the discussion and results.

What are the select criteria suggested by BREEAM CfSH, PassivHaus and LBC that provide sustainable benefit without increasing cost?

By analyzing the criteria and design aspects and divisions of each system, this research's literature review should conclude by summarizing each scheme's main points of focus and how it tackles them into a simplified form by showing which strategies mark as passive, which ones mark as active and which are categorized to be high-tech or not cost friendly.

Is a combination of criteria and strategies from the three different systems capable of reducing emissions and energy use to comply with worldwide protocols?

Further to the summaries conducted, the research should take upon pairing and matching the appropriate criteria and strategies, since each of these schemes performs using a different target, certain aspects are bound to overlap and satisfy others in another scheme, while other aspects might contradict or enforce certain restrictions.

The ultimate question asked by this research in the author's opinion would be as follows:

Is binding sustainable design within the restrictions of rating and accreditation systems the best possible design solution, or would using the best of each world at the cost of losing a certificate of accreditation the sustainable option?

Ultimately after the comparisons and laying each set of possibilities over the other, metaphorically in a similar way to laying transparent paper one over another, the author and research would determine using empirical study, financial, carbon and energy calculations, which approach would be more suitable and identify if it violates one of the three systems.

1.5. Delimitations

Due to time restrictions during the period of this research and a number of key projects that met criteria for case studies are either undertaking construction, evaluation work or are simply unavailable due to privacy restraints, case studies have been analyzed through information provided by their respective consultants, construction firms or online portals that cater to providing the information about the chosen case studies.

- Also to maintain aspect on the design aspect of this research, the main focus of the research project; sustainable design strategies, the project will only consider the design requirements of the schemes. There will be no consideration to the construction and post-construction phases of neither the case studies nor the strategies stated by the schemes.
- Whilst BREEAM CfSH code three is considered part of the UK building regulations, there will be no consideration to the building regulations and their specifics that would draw the project out of focus.
- Complete simulations run over the results of this research might not be feasible due to time restrictions. Estimations will be drawn however during the analysis chapter as to the estimated reduction in energy and / or carbon.

However despite the limitations, the results of this research shall be conclusive as to satisfy the primary aim of this research, which is to draw a set of guidelines for further detailed research which would potentially create a new set of standards for an optimum sustainable residence, or create a bridge of compromise and develop a framework between the existing sustainable design assessment tools and standards mentioned in this research; BREEAM Code for Sustainable Homes, PassivHaus & Living Building Challenge.

1.6 Aims

The main keyword of this research is to optimize, optimizing criteria and strategies, optimizing efficiency in design and optimizing the opportunities presented by currently available sustainable schemes into a more holistic collective of criteria.

But for this research to reach its primary potential, a set of objectives had to be clarified, the initial path leading towards the metaphorical stepping stones of future development, the path being marked by a set of objectives to be realized during and concluding with the research and the its short term goals: During the research the following objectives will be met:

- A critical discussion and interpretation of data from literature review, extracting and formulating of a summarized list of criteria from the following schemes.
  - Living Building Challenge
  - BREEAM Code for sustainable homes
  - PassivHaus
- A critical investigation through cross-case analysis of case studies certified under each scheme, understanding the strategies followed to achieve the criteria required.
- A discussion shaping the result of that analysis, concluding with a diagrammatic representation and a table detailing the results as a set of guidelines.

Finally, as mentioned previously, the ultimate goal of this research over a long term time frame is to allow the boundaries of sustainable design to grow beyond commercial measures (Hahn, 2008) and to be further critically and scientifically predicted, calculated and empirically proven. Then scientifically tested, and analyzed through detailed and organized experimentation to reach optimum results.

Chapter 2

Theory and Methodoly

This chapter will start by discussing and critically analyzing the background literature upon which the assessment systems were design. Additionally the second chapter discusses the theoretical and cross case analysis methodology adopted by this thesis project.

2.1 Introduction

Since the inception and coining of the definition of sustainable development as coined by the Bruntland Commission in its report in 1987 as "1. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNWCED, 1987), worldwide efforts have pushed towards delivering sustainable technologies and buildings. Stretched by the current needs of the population and the limits of current technology.

By following up on the information formerly mentioned, there is a repository of opportunities hindered by the sole focus of these systems on one aspect of many, one aspect of a bigger picture that creates a sustainable building (Faulconbridge, 2015). This research outlines the possible benefits of resource generation within a residential housing project and communal generation, not including large scale flats, which includes its net built footprint and green footprint within the site, with additional to the communal footprint which can be shared by more than one house to provide energy and electricity generation potential as shown in Chapter 6 case studies.

By ultimately creating a policy of maximum area per plot that feed into generation, the concept of "small deeds add to a greater well" is manifested and thus drastically reducing the energy and supplies provided by the grid and municipal resources (Izquierdo, Rodrigues, and Fueyo, 2008). By overcoming the initial cost, and focusing on optimum decisions during the design phase to assure the maximum efficiency per component suggested, this research hopes to put comprehensive sustainable design on the radar by being impartial to any schemes that have been developed over the last two decades.

This ultimate long term goal of this research is to present guidelines for a framework that are to lay ground work for a holistic sustainable design standard and certification system for housing and residential design that can be applied to the United Kingdom by adapting it to standards viable at the time of development, or adapted using local and national data in other countries using research targeted to their locality. The intention of this research is not to point at faults in any of the current systems and criteria that are enforced by the UK building regulations, those which require a compliance of Code level 3 at the time of this research. Neither does it aim to do the same to other systems currently in process of adaptation within the UK, such as PassivHaus (Passive House), product of PassivHaus Institute in Germany. This project's goal is not to judge or rate holistic systems such as BREEAM or LBC a higher standing than others, nor does it try to belittle any of them.

In fact the argument of this research is focused around an ideology that supports micro generation; self-reliance and using multiple benefits for a greater goal. This research will look into the major contributing schemes in the UK; BREEAM Code for Sustainable Homes and PassivHaus, in addition to the Living Building Challenge. By extracting their focal points, ideologies and some of their criteria, some of which can disqualify one system from being accredited by the other, and introducing them under a unified umbrella, and adapting them to the rigid concepts of the living building challenge, this research would ideally pave a pathway into a new true net zero sustainable housing standard.

2.2 Sustainable Assessment

Sustainable buildings are broadly described as buildings that adopt the four construction pillars of sustainability, society, economy, ecology and technical sustainability, the fourth of which encompasses the use of appropriate structure systems and construction methods to provide durability and strength (Rwelamila, Talukhaba, and Ngowi, 2000).

To identify the different modes of assessment systems, one must address the targets and goals they tackle. Each assessment system revolves around a certain target it aims to achieve, these are usually one of three targets as classified by Wall and Hastings (Wall and Hastings, 2009):

- Schemes that address energy consumption by the different systems in the house during operation, often causing a rise in initial cost, titled the Cumulative energy demand systems, an example of which is PassivHaus.
- Another type of scheme addresses building life cycle and life cycle emissions, aiming to reduce carbon impact caused during construction, choice of material and operation. These systems are addressed as Life Cycle Analysis Systems, BREEAM follow that ideology.
- Third and last, Total Quality Assessment systems, which target the three main pillars of sustainability – economy, society and ecology-, these systems often put into account a certain carbon or energy goal that must be achieved in order to consider the system efficient. The Living Building Challenge is considered under that title, despite it being a purely design oriented (Kibert, 2012) standard rather than technical and construction like the other two systems.

Due to this summary, this thesis project will be using the Living Building Challenge as the base print upon which strategies from BREEAM and PassivHaus will be traced on in order to extrapolate a comprehensive, practical and sustainable set of guidelines for Sustainable Architectural Design.

This section will start by identifying the differences between the two terms used previously; ones that are to be essential to identify the modes of which the three schemes that will be discussed in the following sections of this chapter. By stating the term standard, it is to refer to a set of tested regulatory practices that are to ensure optimized results, in terms of building standards, which would ideally include the complete building process from design, construction, and occupation to end of life.

These could be in form of a rigid standard which if followed, would grant a certification such as PassivHaus/Passive House and the Living Building Challenge. Its standards are strict and require exact compliance to be rewarded with the certificate associated with it. On the other hand, these guidelines could be applied into a rating system, which incorporates a plethora of criteria parameters, or degrees of compliance as to how efficient they perform and the necessity of further efforts put into increasing the level, such as the Building Regulation Establishment Environmental Assessment Method, BREEAM, to be precise, the code that is to be analyzed in this this thesis, the Code for Sustainable Homes.

2.2.1 Sustainable Assessment Methods

A. Cumulative Energy Demand Systems (CED)

CED assessment systems advocate the estimation, calculation of energy demands –in pre-design phases-, and the evaluation of the building’s energy consumption after construction, these demands are made to cover some or all of the building’s life-line needs such as space heating & cooling, ventilation, communications and lighting. The specifications in place however can partially or fully cover these aspects depending on its focus.

Requirements in this type of systems often derives from a series of calculations and proposals, leading to a fixed energy figure to be achieved over a fixed measure of time, one year being the common measurement, however through a series of proposals, monthly, quarter annually and other intervals were offered as options, but the confederation of central European countries settled on the use of the annual system, using energy figures noted as kWh/ m^2 per year. The specific energy needed to heat (or cool) one standardized meter square of the project over the course of a year (Marszal et al., 2011).

As the case of PassivHaus, it utilizes the annual energy required for space heating and cooling, paired with a rigid requirement of air-tightness and thermal insulation, in addition to a maximum amount of energy utilized for all the building’s remaining functions, without specifying how the remainder is to be divided, while the current energy specific demand of UK housing stock averages on 300 kWh/m2.a (Butera, 2010), which includes a specific heating demand of 153 kWh/m2.a (Birchall. et al., 2014), the urgency of creating rigid criteria in order to support the gross national energy demand is at a peak. It is a sound judgment to orient design efforts into reduction of operational energy, as per figure1, showing operational energy contributes to an average of 85 - 90 % of building’s life cycle energy consumption (Ramesh, Prakash, and Shukla, 2010, Suzuki and Oka, 1998).

However while that approach does not satisfy the notions of Net Zero Energy Buildings on its own, it however does assist in making the task feasible, by accounting for embodied energy in materials during construction, the energy consumed during construction, and by providing suitable compensation with appropriate micro-generation techniques, the task of net zero or even net positive generation is not far-fetched (Hernandez and Kenny, 2010). It is notable to mention, as well, that the Living Building Challenge while does not have specific energy criteria per function within the building, it does adopt a

Net Positive Plan (Cole, 2014), which can be extrapolated from the PassivHaus system in order to optimize and facilitate achieving that target.

B. Life Cycle Analysis Systems

Life Cycle analysis systems shed their light in different colours, they can be assessed in form of Environmental Risk Assessment (ERA), Material Flow Accounting (MFA), or more commonly used, Life Cycle Analysis (LCA). Life cycle assessment according to code, is performed on three stages after defining the goal and scope of the procedure, 1) Inventory Analysis, 2) Life Cycle Impact Assessment, 3) Interpretation and Improvement phase (ISO 14040, 2006). As defined by the ISO document, life cycle assessment requires a focused element, an item within the product's cycle, dwelling in this case, that is to be traced throughout from cradle to cradle. (Finkbeiner et al., 2006). However opposite Finkbeiner et al's conclusion, and by implementing two forms of life cycle assessment, creating a hybrid system between Environmental risk and Life Cycle analyses, and creation of a hybrid system, the limitations of LCA can be overcome to produce more holistic results (Haes et al., 2004) which is what has been achieved through the green guide's Code Mat 1 & 2 Material calculators, further explained in chapter 5.4 of the BREEAM CfSH analysis, subsections C.i and C.ii under the material category.

C. Total Quality Assessment System

As previously mentioned, TQA systems advocate a multitude of categories, mainly summarized as the three pillars of sustainable design, Environmental issues; such as climate change, emissions and energy consumptions, Financial consideration including initial costs, operational costs, long term profit from high initial cost investments, and finally Equity and Social aspects, which encompasses transportation, social equality, happiness within surroundings, healthy atmospheres, educational buildings and in general, the quality of usable space within a project or structure (Berardi, 2011) . The more used systems are generally categorized to be multi-categorical systems, where each category is composed of a number of criteria, given a range of compliance levels with possibly assigned scores. The building's overall quality is later assessed by summing the total of points produced through the scheme, primarily through pre-construction calculation and often verified by post-construction such as BREEAM (BREEAM and DCLG, 2010), or by using the previous two methods in addition to post-occupancy evaluations such as Living Building Challenge (LBI, 2015). This project will use the rigid yet technically flexible Living Building Challenge as groundwork upon which elements from BREEAM's technical criteria and PassiveHaus' energy and fabric specialized criteria will be interlaced, doing so in an attempt to create a holistic sustainable design framework. The result of this research will fit together the assessment systems mentioned in the previous section; bridging the gaps between them, using the preferable and more technically rigid and efficient methods to extrapolate what would be a stepping stone to a holistic sustainable set of criteria and guidelines unbound by the commercial values and race for certification caused by the goliaths of sustainable assessment industry (Hahn, 2008) .

2.3 Methodology Outline

The research follows the three schools of thought which require investigating the context of a problem; its target audience and whom it might affect, the reason directing this research down its path and finally the literature review that provides insight into the problem, its solutions and accuracy of claims (Groat and Wang, 2013). The collective of these approaches help formulate and create precise problem questions which in turn assist with finding the answers within the literature and adapt the preliminary answers through the researcher's pen into discussions and conclusions.

This research will be conducted using the mixed research method (Kiessling and Harvey, 2005, pp. 22–45), by adopting both qualitative methods within literature and guidelines, and quantitative methods extrapolated from published analysis and case files. Subsequently; the research will be divided into three steps, starting by an introduction and review of the available definitions and literature that contribute to this project, thus understanding the kinds of systems available to be able to categorize the ones being reviewed in this document.

Progress on this project is divided into three main phases or steps, taken to ensure impartial and comprehensive results upon reaching the discussion phase.

> **Phase One**: A critical analysis of PassiveHaus, BREAAM and LBC regulations, summarizing the issues and points from an architectural and sustainable designer's point of view; without straying into construction and technical specifications. This is accompanied by a brief theoretical study of behavioural impact of users and their usage tendencies through published survey and governmental reports.
>
> **Phase Two**: Due to time and privacy limitations, a phenomenological study that addresses behavior and observation of the current occupants of the provided case studies cannot be performed. Thus a cross-case analysis has been adopted, by turning to relative literature and reviews of previously performed case studies and post-occupancy evaluations so a relative picture can be painted as to draw viable conclusions (Meir *et al.*, 2009, pp. 189–219).
>
> **Phase Three**: A theoretical empirical desk top study will follow focusing on assessing and estimating the savings and reductions that can be achieved by performing a proposed set of guidelines.

2.3.1Theoretical Approach

In order to conduct this research, a theoretical approach has been adopted to look into the criteria, strategies, theories and knowledge that governs the sustainable analysis field. By primarily referring and studying the source files and documents released by each of the studied schemes, a comprehensive and direct understanding of their values can be acquired. These documents primarily are as follows: The living building challenge v3.0 documents (LBI, 2015a-g) acquired from the Living Building Challenge website through a paid subscription, as well as referral to their community support section and website information. The BREEAM Code for Sustainable Homes technical guides 2006 and 2009 (BRE, 2006, BRE and DCLG, 2010) acquired from the BRE website. And finally the PassivHaus, through the PassivHaus Handbook (Cotterell and Dadeby, 2012), the PassivHaus resource webpage, created by the PassivHaus Institute (PHI, 2013), in addition to their reports and a study of PassiveHaus planning package examples.

A critical analysis and interpretation of the 3 schemes is to be carried out and interpreted throughout this thesis project. By reviewing journal articles, reviews, dissertations, books and building reports performed on the schemes, their certified buildings or relative topics and comparisons. In addition other sources such as reports published during EcoBuild 2015, reports published by climate and environmental agencies around the UK and the world, awareness websites and scientific establishments' digital methods of output were viewed, referred to and used to support up-to-date information regarding statistics and markers.

2.3.2 Case Study Methodology

The choice of case studies in this research is of both descriptive and instrumental value (Baxter and Jack, 2008); they are descriptive in a way that they represent the criteria and strategies implemented into their design, creating a holistic view of the theory in motion (Stake, 1995), they clarify the ideas and the mechanisms that make a certain assessment scheme operate within real life parameters and variables; not just theoretically and through calculations (Yin, 2009). However it is also instrumental in elaborating and describing how the case study along with the strategies and knowledge behind it would further contribute to the knowledge at hand. By placing all the theory on equal levels, as applied into the field to facilitate perception and understanding; aiming to achieve another goal that is partially reliant on these remarks.

In this instance, understanding the application of the three schemes into their respective case studies assist with assessing the criteria compatibility as part of the final perceived outcome of the research.

Hence, to perform this research, case studies and cross case analysis will play an integral role into understanding the criteria and mechanics applied to create these structures holding the certifications they do, and not the tallying nor scoring system calculations used to reach the certificate, as shown in the following chapters upon reviewing the literature and chapter 7 upon completion of each case study.

2.4. Thesis Structure

The thesis follows a simple sequential progress as shown in figure. It starts by analyzing the theory being sustainable assessment systems, progressing towards critically analyzing the three chosen assessment tools (LBC, PH, CfSH). Progressing towards a cross case analysis of case studies, deducing and comparing output and methodoly, thus formulating a set of guidelines.

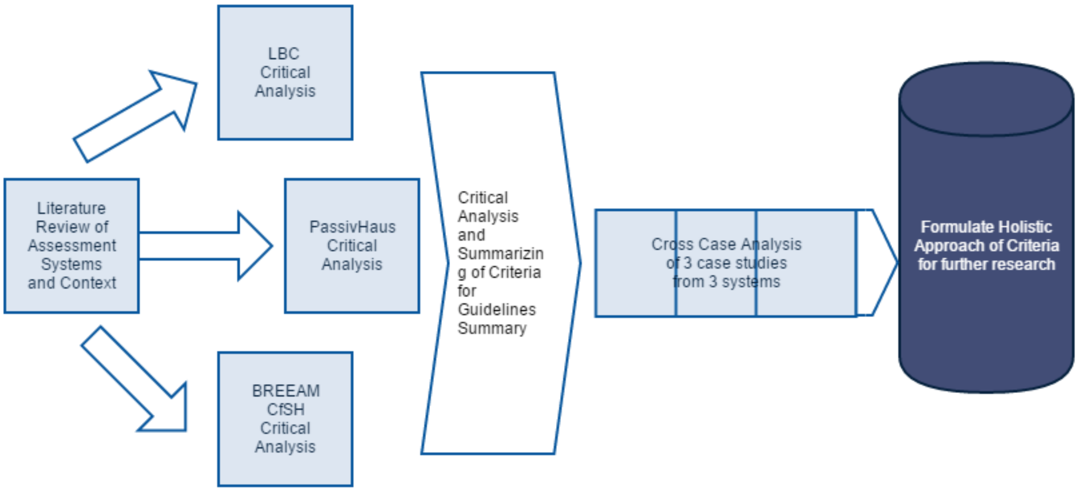


Figure 1 Diagram showing sequential process of the thesis

Section 2.5. Vital Keywords, Definitions, units and terminology

This section was will provide insight to the unified system of units used within calculations, guideline manuals and criteria. Since the PassivHaus and BREEAM CfSH standards adapt an empirical and analytical approach towards achieving their criteria, they require a set of defined criteria and values to be achieved in order to meet their requirements. However for the sake of summary, units used in LBC will be included in this table. These values and criteria are purely mathematical, built upon laws of thermodynamics and fluid mechanics, used within theoretical calculations, simulations and verifications for post occupancy evaluations, thus they are annotated with specific and accurate units, derived from and included in the International system of Units (SI Units), to facilitate design process.

Units dominated by a certain system will colour coded as follows.

Living Building Challenge will be coded in the Orange tone of their scheme.

PassivHaus will be coded in the Red tone of their scheme.

BREEAM CfSH will be coded in the Green tone of their scheme.

Keyword	Description
Areas (ex: Floor Area, Site Area, Usable area,etc) m^2 and	Areas are calculated according to their geometric form and are represented in meters squared m^2 . Used in all systems to determine exposure, calculate volumes m^3, thermal conductivity of surfaces and other calculations.
Volumes (m^3)	Calculated according to volume, used to denominate air change volumes as well as water and gas usage.
Carbon Dioxide emissions (kg CO2 per m^2)	The calculations for carbon dioxide emissions are important in determining the building's carbon footprint, an important aspect in this research due to the holistic approach adopted. Thus materials are required to be chosen appropriately taking into consideration the compromise between their durability and carbon emissions.
Specific Energy Use (kWh/m^2/yr)	Used to determine the energy output required to heat (or cool) a modular meter squared of treated floor area (TFA), over course of a year. It also appeared in the LBC as kJ/m^2/yr. Given that 1 kWh = 3600 kJ.
Air Changes per hour (ACH)	One of the essential values focused upon when designing a passivhaus building, the value reflects the amount of air entering the space (air flow rate m^3/hour) divided by the total internal volume ventilated. The value has no unit, and is noted in a manner such as: 1.0 changes/times per hour. This measurement is performed at 50Pa (pascals) in PassivHaus testing (Cotterell and Dadeby, 2012, Thomas, 1999)

Air Flow Rate m^3/hour	It's the measure of the flow rate of air into and then exiting a building during one hour. The value is deduced by a number of equations depending on opening placements, wind velocity upon entry and areas of openings. (Cotterell and Dadeby, 2012, Thomas, 1999)
Air Permeability (m^3/hr/m^2)	It's the measurement of air flow in meters cubed, through the building's membrane per meter squared of fabric elements (walls/ floors/ roof/ windows/ openings).
Thermal Irradiance (W/m^2)	The amount of energy radiated by a source or through a surface, such as solar irradiance for solar passive design or heat emit by bodies and devices within space.
G-Values	It's the total solar heat gain divided by the incident solar radiation, used for windows that are 90º to the horizontal (i.e: vertical). It's a factor in calculating the total solar gain a certain area of window will provide using a certain type and quality of glazing and framing. Since it's a ratio, it is unit-less and expressed between 0-1. With the ideal PassivHaus value **being ≥ 0.6**
Ug-Value	It's the U-Value measures of the glass pane alone through its center. PassivHaus buildings require a value of **0.75 W/m^2K** for vertical openings and **1.0-1.10 W/m^2K** for sun roofs and inclined windows.
Psi-Value Ψ (W/mK)	Measure of calculating energy transfer through a linear element such as thermal bridges in PassivHaus calculations. (MCRMA, 2006)

Chapter 3. Understanding the Living Building Challenge

This chapter will critically analyze the Living Building challenge, its challenges and criteria, concluding with a summarized table and diagram of the conclusions.

3.1 Context within Thesis

The Living Building Challenge and its imperatives were chosen being part of the most comprehensive category of assessment systems, the Total Quality Assessment (TQA) system, enforcing a set of standards, or imperatives as referred to in this scheme, which encompass all aspects of sustainability, Carbon offset, energy usage, ecology, site, users, society and health (Todd et al., 2001). Thus due to the inclusion of all the values that account for sustainable design, and pushing the limits of designers and builders past the strong yet gradually lenient criteria of other TQA systems like BREEAM (Momberg, 2013), through a set of rigid requirements. The researcher has chosen to use the broad components (petals) of the LBC upon which this research can begin building more specific, design oriented strategies to create a holistic set of guidelines as outlined by the aims stated previously. However this chapter will only pertain to the critical analysis of the LBC, further description of how the LBC serves as a base pattern for integration with the other systems will be discussed in chapter 7.

3.2 Introduction

The Living building challenge is a rigorous standard and assessment tool created as part of a project originating in the mid-1990s by Jason F.McLennan and research partners, first published in 2006 (LBC, 2012). McLennan has been an advocate for sustainable design, a recipient of Buckminster Fuller reward, in addition to starting by his firm that specializes in delivering sustainable buildings (McLennan, 2009), the initiation of LBC and International Living Building Institute In addition he led the creation of a material rating software for companies and designers called Pharos (Healthy Building, 2014), Declare; a base material disclosure label for building product in addition to five books that advocate sustainable design and LBC approach. The project to create a truly sustainable was done in collaboration with the Cascadia Green Building Council producing the Living Building Challenge v1.0. The LBC was launched as a way of creating an economically viable model of a Net Zero -and ultimately a Net Positive building- that is to be sustainable in all values of sustainability, economy, equity, socially and financially within UK standards (Cole, 2014). Due to the rigid regulations of this standard as well as the lengthy process of registration, monitoring, assessment and certification, there have been only eight fully certified buildings since 2006 and eight partially certified petal projects and twelve net zero energy certified projects (Living Future, 2015a), in addition to 210 certified or partially certified privately-marked projects that cannot be accessed for case study files (Living Future, 2015b).

This chapter will approach one of the more rigorous certification tools, being designed without constrain to any one building type and versatile in its application since it permits enough space to implement local regulations as well as other systems the customer wishes employed (Kwok and Grondzik, 2011). The Living Building Challenge adopts the concept of a building working against its own negative impact, enforcing net-zero structures as a minimum requirement in most imperatives, and requiring net-positive as a mandatory requirement for the “Living Building” certification.

There are different acquirable titles under this system, using the set of imperatives this tool provides, furthermost and the highest certification is the Full Living Building Certification, ensued by Net Energy, and the individual petal certifications, these are structures that have satisfied one or more of the petals, and are most likely awaiting a final audit to be fully certified. The final certification is Net Zero Energy certification, which requires the building to achieve net zero energy over course of the year through energy efficient features, electricity generation and passive design (Living Future, 2015a),.

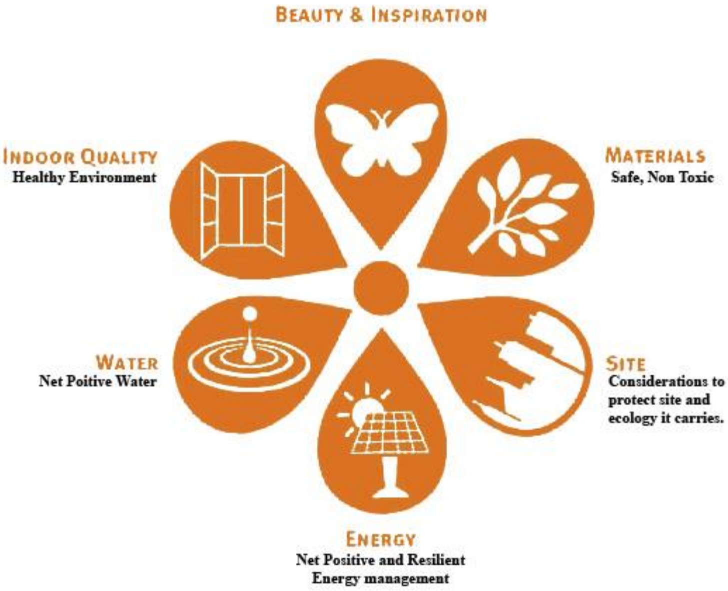
While there are currently no fully certified living houses to be used as a case study, 2 housing projects satisfying a number of the petals will be used as case studies, outlining the material, emissions and energy, as well as the strategies implemented that have qualified it for the petals.

This paper’s analytical and comparative section will be divided according to the multiple petals, or assessment criteria set by the Living Building Institute; it is notable that the LBC uses the term Petals to define its Categories and Components (table 3), and uses the term Imperative to identify the criteria within each Category:

Table 3 Table summarizing the seven petals of Living Building Challenge

I. Place	**II. Water**	**III. Energy**
IV. Health& Happiness	V. Materials	VI. Equity
	VII. Beauty	

(LBI, 2015f) in each subsection. This section will provide a descriptive analysis the different petals of the living building challenge and their underlying imperatives through the literature provided on the LBC website and community sections through the Living Building Challenge v3.0 introductory document, petal handbooks and community forums which the author has a paid subscription to access. Through each section, a descriptive summary will be held to each imperative outlined by referencing the petal handbook and standard guidelines and citing any appropriate academic literature. A critical commentary will outline the restrictions of this scheme if implemented solely, and a further summary of the values which are to be carried on to the analysis and discussion chapters of this thesis project.



This figure summarizes the approaches taken within a metaphorical figure, since the LBC uses petals to describe its categories. All of which participate into the final fair form and the efficiency of the flower.

3.3. Keyword definitions exclusive to the Living Building Challenge

Typology: Typology refers to the scope and type of project being conducted, this helps identify what imperatives are compatible and can be applied to the project (Living Future, 2015c)

- **Renovation:** Projects that are being taken over from a previous non-sustainable state to be rehabilitated into a living building.
- **Infrastructure + Landscape**: Large scale projects that deal with site and site amenities without the availability of structures that need to be enclosed.
- **Building**: Quite as straight forward as the title, it handles buildings that are being incepted and designed using the concepts and strategies of the Living Building Challenge, starting by design and through its construction and occupational assessment.
- **Community:** The community challenge applies to a number of structures that coexist together and operate as part of a neighbourhood, community, campus whilst sharing certain amenities such as, but not limited to, roads, green or community areas.

Transect: The transect concept is an adaptation of the New Urbanism (Katz, Scully, and Bressi, 1994, Talen, 1999) transect planning approach that was developed and published in the Smart Code manual (latest version 9.2) by the Center for Applied Transect Studies (CATS, 2010*)*. The transect smart code benefits from and adapts Smart Growth and New Urbanism strategies into creating a well divided yet adequately mixed community that supports sustainable growth for community, nature and urban development (Duany, Plater-Zyberk and Company, 2009). In the living building challenge, adequate transects for each project must be identified according to footprint and site scale in order to adapt the appropriate imperatives to suit the site as such that it is developed to be a productive part of its context. Whilst that approach allows for a natural flow of urban development, imposing guidelines that regulate form without regard function on a city scale causes complications, specifically when applied on a regulatory scale, some documents might be too technical and complicated as to negate architectural design creativity and hinder functions that occupy these buildings. (Garnett, 2013, pp. 571 – 588). Fortunately within the Living Building Challenge, these concepts are not strictly applied, but are merely regulated in the latest addition in version 3.0 stating that buildings needs to adapt beauty and reflect on their context, but stated exceptions due to local regulations are allowed.

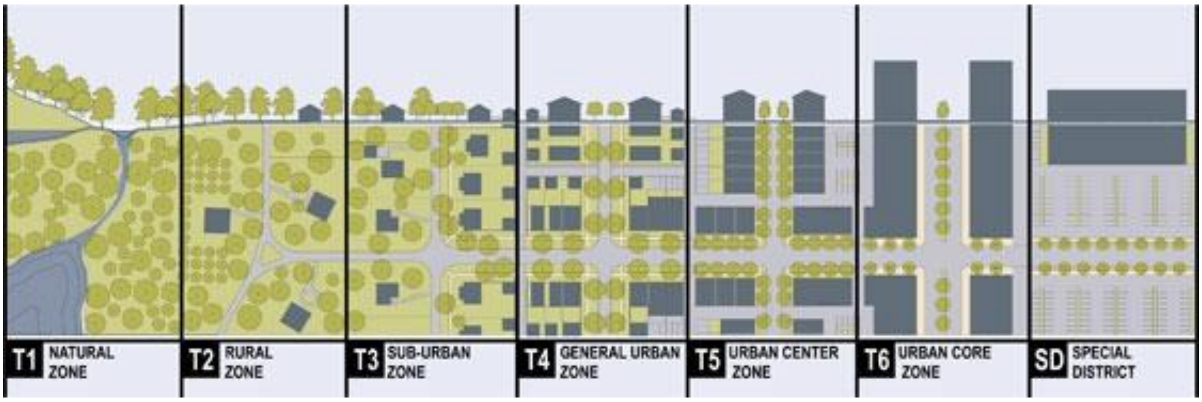


Figure 3 Transect diagram (CATS, 2010)

Scale Jumping: Perhaps one of the more beneficial strategies used by the LBC, scale jumping allows for the communal sharing of site amenities, merged into a larger one accessible by a cluster of buildings that share site borders with one another allowing for communal resilience and sustained production of energy or storage of water (Coyle and Duany, 2010). This allows upscaling of microgeneration by a reasonable amount to be able to satisfy other imperatives.

3.4 Petals and Comparisons

The following section will summarize, discuss and analyze each Petal of the living building challenge and the imperatives encompassed within. Each petal will include its own researcher's remarks and conclusions in addition to reference throughout.

3.4.1 Place Petal

The place petal, formerly the Site petal, addresses the project's setting, including the site, neighbours, ecology and ensures building placement does not harm these surroundings and is suitable for its function. This petal includes all project types despite scale or function. The design and research teams tasked with the project are required to assess their site, identifying its ecology if present and restore it to its former condition after construction. The petal's strategies are oriented accordingly with the Living

Transect assigned to it, as well as the project area or jump scale applied to it, and thus the petal guidebook has been rigidly assigned to ensure that all calculations and certifications have been unified. This process of selection has been facilitated by urging designers to submit their site documentation as early in the process as possible, to assess and assign and living transect and provide guidance for further steps.

The place petal includes 04 Imperatives, listed briefly in table 4;

Table 4 Place Petal Imperatives

01. Limits to Growth	**02. Urban Agriculture**
03. Habitat Exchange	04. Human-Powered Living

Imperative 01. Limits to Growth. This imperative glorifies the most basic and important requirement of sustainable development, durability, which while is applied to structures and systems, is also first and foremost, in the benefit of this planet and its future inhabitants. The imperative ensures that any construction or development does not intrude on the natural ecology of the place. It sets a number of regulations to protect sensitive ecology or sites with a risk of natural disaster to ensure resilience of ecology, occupant and structure.

As the first of many rigid requirements, the right to growth petal starts by listing a number of sites forbidden for construction which would require severe compensation in order to allow construction on, which include wetlands, prime agricultural land, virgin prairies, dunes or old growth forests (LBI , 2015f) . To construct on these high value ecological sites, a set of guidelines were established in order to preserve and maintain these habitats. Such as reconstructing a habitat identical to one destroy, saving all the species of fauna evacuated and replanting the flora extracted as well. Not only does the imperative address nature's right to grow, but also the users', by prohibiting construction of any buildings over the 100 year flood path (Coyle and Duany, 2010), encouraging proper research into the location; serving as a reminder for longevity, one of one of the core concepts of sustainability. However the imperative does promote the reclamation of brown and grey fields, sites that are contaminated by pesticides or invasive species, and sites that have been made usable as paths or parking lots respectively. It also placed the use of petrochemical pesticides and fertilizers on its "Red List" (LBI , 2015e), as completely prohibited to be used in any way to maintain or remedy on-site landscape.

Imperative 02. Urban Agriculture, governing and forcing a mandatory criterion where any site development must adapt a certain area for agriculture (Mougeot, 2000). As per all imperatives, area calculations need to be at hand, this one in specific requires the Floor Area Ratio, calculated by the following formula, Gross Square Meters of Development / Total Area of Plot. This formula is used to determine how much area is required per development for agricultural purpose, to produce food for the users and for the community. In addition to that, it requires any single family home is to be able to store two weeks of food for the full number of occupants, assuming 2000 calories per person per day, or by more adequate nutritional calculations. On the other side of this comparison. This imperative in specific would help residents of deprived regions or countries, one without access to or ability to purchase clean fresh food (Maxwell, 1995).

Imperative 03 Habitat Exchange, also known in construction fields as Ecological Compensation (van Bohemen, 1998), acts as an extension and clarification for Imperative 01, this section is associated with protecting conservation areas or high value ecosystems that might be hindered by construction of any sort, for example, constructing an outpost for a wildlife reservation (Skabelund, 2015).
Any intervention in these zones constitutes submission of documents regarding the value of these ecosystems, setting aside portion of the project site for these systems and contacting the Living Building Habitat Exchange program, who in turn contacts the appropriate wildlife society to relocate and rehabilitate whatever damage has been done due to development.

Imperative 04. Human Powered Living (Perry, 1995), encourages .involves the promotion of pedestrian communities and ones that support a healthy transportation system, one that does not render the site inaccessible or hinder its mobility or density (LBI , 2015f). Most of these considerations advocate for safe stowage of bicycles and cars, sheltering for walkways and pedestrian routes, and promoting human powered vertical and horizontal transportation such as stairs and ramps in hope to persuade residents to use sustainable and energy-free modes of transportation within smaller and village-scale communities (Nelson and Allen, 2015). Version 3.0 enforces the presence of a circulation and mobility plan in addition to alternatively fueled transportation, bicycles and at least one electric car charging port. A scheme that is definitely targeting for a future governed by walkable communities and has foreseen the widespread of electric cars, especially after their recent spread in the UK. The Human Powered Living Imperative encourages calculations and guidelines to calculate exact cycle storage facilities to cater to users empirically, and while there is a minimum amount of 15% of building users, using local regulations or rules derived from design references is required(LBI , 2015f).

3.4.2 Water Petal

The water petal governs the production, use and disposal of all fluid and water based materials on site, including potable water, grey water, black water, storm and rainwater harvesting, managing it, storage and disposing of the excess.
Containing only one imperative, 05. Net Positive Water in version 3.0 (LBI, 2015g), the imperative advocates the compatibility between water systems on site and natural water systems depending on site and climate. As advocated by the title, net water positive imperative requires that the water system must

be part of a site-closed loop (Cole, 2014). Harvested on site by different means, such as rain water harvesting, condensation tools, waste water treatment, ground water supply or other open water sources. This imperative in the UK is easily achievable due to the precipitation rate year-long, thus not requiring a large sized collection and treatment facility (Chambers et al., 2015). Water monitoring in the building has to be done as strictly as possible to be able to evaluate use from every appliance or plumbing outlet in the house. Furthermore monitoring of harvested, stored, treated and disposed water must be monitored as well to provide for a fair assessment. Projections calculated through that system are put to the test over a twelve month post occupancy evaluation after which the project can be credited with the water petal as long as it maintains a net positive value.

It also promotes the jump scaling of this imperative to benefit surrounding sites, where a cistern or a unified water storage can be shared between multiple sites, the community, ecosystem or agricultural land. Concluding the water petal, due to England's Koepen-Geiger climate zone being Cfb, one that has an average of 800mm annual rainfall during the whole year (*World Maps of Köppen-Geiger climate classification*, 2010, Kottek *et al.*, 2006, pp. 259–263), applying an efficient water harvesting strategy is a feasible and overly achieved challenge, the problem would arise with treatment and storage of harvested water, limited by site area on smaller plots, which in turn creates opportunities for scale jumping and providing communal benefit.

3.4.3 Energy petal

Just like the Water Petal, managing resources in the Living Building Standard have taking a developmental step towards net positive, thus as an upgrade from v2.1 of the Energy Petal that advocated Net Zero energy to the new Energy Imperative 06. Net Positive Energy (Cole and Fedoruk, 2014, LBI, 2015a).

The imperative demands an excess of one hundred and five per cent (105%) of the project's energy requirement to be supplied and generated on-site (Cole, 2014). The importance of that percentage is to provide resilience for the users, providing stored energy to be used during night time and other emergencies. A minimum of 10% of building's essential lighting load as well as refrigeration is required to be stored at all times, able to last up to seven days, due to emergency situations or sudden spikes of energy use within the building. (LBI, 2015a). A formidable challenge in the UK; given the country's low solar exposure and low number of annual daylight hours, reaching an average of 1493 hours of sun per year (Current Results Weather, 2015) making the return to solar origins concept adopted by LBC a solution that is financially taxing.

What makes this imperative and standard in general as strict as it is, is the prohibition of combustion, burning any material such as biomass, biofuels, alternative or conventional fuels. The possibility of harmful gas in addition to greenhouse gas emissions despite of any amount despite how miniscule and despite how efficient the combustion module is puts combustion and combustibles on the red list (McLennan, 2010).

3.4.4 Materials Petal

The materials petal aims to create a future of materials economy that is non-toxic, regenerative and avoid any negative effects on occupant's health (Wallace et al., 1987), the material petal aims to use materials that can be re-used while eliminating the concept of construction waste while staying financially viable, functionally efficient and aesthetically pleasing (LBI, 2015c). Production costs, sourcing, transportation distance and the general economy, create an obstacle that needs to be overcome, but the LBC attempts to counter that challenge by creating a guideline to follow that will allow achieving its targets without any negative impacts.

The materials petal directly influences and supports the Health & Happiness Petal since the use of adequate and toxin-free materials support the material petal certification, thus directly leading to the ultimate outcome of Health and Happiness (Wallace et al., 1987, Mensah-Attipoe et al., 2014).

The Material petal is composed of five imperatives shown in table 5:

Table 5 Material Petal Imperatives

Imperative 10. Red List	**Imperative 11. Embodied Carbon Footprint**
Imperative 12. Responsible Industry	Imperative 13. Living Economy Sourcing
Imperative 14. Net Positive Waste	

Imperative 10. The Red List aims towards the elimination of the worst materials and chemicals as it dictates, ones with the greatest negative impact to occupant and ecological health (Wallace et al., 1987). The list includes a large number of petroleum products, polymers and compounds that contribute to volatile organic compounds (VOCs) spreading in construction as well as other harmful chemicals that lead to a number of physiopathological mechanisms, respiratory diseases and disorders they might cause to occupants (Fernández *et al.*, 2013, pp. 22–27) including but not limited to symptoms such as irritations, coughing and respiratory symptoms, nervous symptoms such as headaches and fatigue, dry skin and other symptoms users might take for granted or under-estimate to be prompt yet prove even more harmful on the long run (Wolkoff, 2013, pp. 371–394). Ideally, the red list has been developed and is constantly updated to comply with the Material Health scoring system that identifies and rates

materials on a Cradle to Cradle basis in the C2C version 3.0 (C2C, 2013, Harrington, Klosterhaus and Bezark, 2012) Furthermore, the use of these materials in air-tight buildings in addition to heat building, low ventilation rate (without purge ventilation) causes a higher rate of decay and dispersion of these materials into the space and thus their toxic concentrations (Huang, Xiong, and Zhang, 2015, Mensah-Attipoe et al., 2014).

Imperative 11.Embodied Carbon Footprint is one that certifies the building's Life Cycle Analysis in terms of embodied carbon dioxide emissions from all the building's materials and operation in a cradle to cradle scheme starting from inception, design to operation to decommission or renovation (Braungart, McDonough and Bollinger, 2007, pp. 1337–1348).This approach helps assess, project and aim to reduce carbon and energy reductions that can be achieved through different strategies during the design and analysis phase to understand how the building affects its environment on the long run (Kneifel, 2010, pp. 333–340, Bribián, Capilla and Usón, 2011, pp. 1133–1140).
By completing a holistic life cycle analysis through one of the carbon calculators provided or through an independent or governmental assessor, such as BREEAM certified assessors, the design and analysis team is able to understand the carbon offset caused by the building over its lifespan, which is set to be 50 years by the LBC. A carbon positive building, produces more embodied carbon dioxide than it absorbs during construction and thus has a negative impact on the environment. Subsequently, the carbon offset program was initiation, by buying carbon offset from certified partners, money paid per year is directed towards research and countering the emissions produced by that building (Nadaa, 2006). However that system is faulted, since most projects tend to prove their offset payment for the period required to gain certification then stop paying afterwards, and since embodied carbon is calculated per ton per annum, the project continues to produce positive carbon during the following years and breaching its sustainable agenda in a hypocritical scheme (Jacobsen, 2011, pp. 67–78).

Imperative 12. Responsible Industry and Imperative 13 Living Economy Sourcing and Net Positive Waste are related when it comes to the overall concept, all three imperatives call for sustainable, proper sourcing of materials. Processing has to be transparent and declared, sources from sustainable or renewable sources dedicated for farming or reclaimed through cradle to cradle or recyclable schemes (Halliday, 2008). The Living Economy sourcing dictates that materials must be sourced from up to 5000km, with a 25% allowance of being sourced from any place.

However applying that concept the UK would be impractical, since the maximum distance between the furthest two points in mainland UK, between Land's End, Cornwall to John o'Groats in Caithness, Scotland is 970km (OS, 2015) as measured by ordinance survey grid point references. Such distance has to be either refined to accommodate the size of Mainland UK, or consider the expenses and emissions produced by importing from European countries that might be able of sourcing some materials also known as Carbon Leaks and Carbon Exports (Davis and Caldeira, 2010, pp. 5687–5692, Kuik and Hofkes, 2010, pp. 1741–1748).

The last of the published petal handbooks set in version 3.0, containing imperatives 07 to 09, listed as follows in table 6 the imperatives of the **3.4.5 Health and Happiness set,**

Table 6 Health and Happiness Set

08. Civilized Environment	08. Healthy Interior Environment	09. Biophillic Environment

(LBI, 2015f) This set of imperatives work to provide a psychologically and physically healthy environment for occupants and owners, by creating connections to the surrounding environment (Coon *et al.*, 2011, pp. 1761–1772) and designing and specifying healthy indoor materials.

Imperative 07. Civilized Environment and Imperative 09. Biophillic Environments both share common grounds that contribute to psychological and physical health (LBI, 2015f). Both imperatives aim to create a direct connection between indoors and outdoors, a feeling of visual and a level of physical continuity to provide a feeling of joy and freedom (Ching, 1995). Achieving these targets; by performing adequate daylight calculations to identify any glare spots and daylight distribution without spaces, allowing sufficient daylight factors within the building (Roche, Dewey and Littlefair, 2000, pp. 119–126), in addition to accounting for thermal and visual comfort (Greenup, Bell and Moore, 2001, pp. 45–52), creating connections with the outdoors is an essential requirement in imperative 07 without any possible appeals except for areas of special use or areas that are not frequently occupied.

3.2.5 Equity Petal

The Equity petal (LBI, 2015f), introduced in version 3.0 has limited literature, it includes a table of design guidelines attached in the appendix, of criteria needed to be met or complimented to provide a sense of equality and justice between all users of the project, at any scale, but mostly focused towards the public and living community challenges. This petal is divided into four imperatives and will be briefly described, since they are still under development with no comprehensive guidebooks and are still quite subjective in approach, they will not be given great focus.

Imperative 15. Human Scale + Humane Places and Imperative 16. Universal Access to Nature & Place, sets a number of design guidelines essential to be followed, these guidelines tackle issues such as areas, distances, landscape and urban design to give users and pedestrians a sense of worth in surroundings modelled after the human scale and dimensions (Ching, 1995).Access to place allows general public usage of spaces created within projects to spread the benefit and eventually awareness to the project and value. It also advocated proper access to impaired users, allowing equal opportunities for all users (Thapar *et al.*, 2004, pp. 280–289) , part of the foreseen future by the Living Building Institute.

Imperative 17. Equitable Investment and Imperative 18. JUST Organizations, both of these imperatives tackle the humane side of building occupancy, the investment part dictates donation of a certain amount per dollar invested in the building to a charitable organization. JUST contains a checklist of practices performed by the owner or employed to ensure just treatment of employees and humane treatment and comfort of any users.

3.2.6 Beauty Petal

Last of the version 3.0 newly added petals, contains two imperatives; Imperative 19. Beauty + Spirit and Imperative 20. Inspiration + Education, both of which cannot be empirically calculated and proven (LBI, 2015f), thus documentation of design literature and efforts made to raise awareness of technologies have been suggested and are required to be submit for consideration. However Imperative 20. Inspiration + Education did dictate allowing at least one open day annually for visitors to learn and understand the technologies, techniques and strategies implemented. Appointment of that day has been left to the owner's discretion, along with publishing a website or blog outlining the building's features.

3.2.7 Summary Remarks

This chapter investigated the petals/criteria adopted by the LBC, however despite the comprehensive sustainable approach to design, it lacks in certain petals on defining fixed values or criteria to be met except for prohibited items and guidance for other imperatives. Thus it is concluded that the LBC requires integration with more technical standards to reach its optimum potential and satisfy a holistic design approach. That conclusion is not surprising since the LBC adopts and understands the limitations and building regulations of wherever the project is to be constructed. Thus in the two following chapters, PassivHaus and BREEAM CfSH will be discussed to extract preferable criteria to be incorporated into an optimized set of sustainable criteria and strategies.

It's apparent that the LBC's progressive development towards mending the ecology and surrounding habitat is strongly influenced by a net positive ideology. An ideology driving the architect or designer following the LBC guidelines to push the limits of their project towards self-sustaining and adding value to the building's surroundings and its users (Mang and Reed, 2014).

The following table (table 7) will summarize the petals and imperatives (the categories and criteria) upon which the LBC is built upon to provide a structured and brief set of points to be integrated into the final proposed model in chapter 7.
On the following page, figure 4 shows the template upon which further strategies and criteria will be imposed upon concluding the analysis and cross case analysis.

Table 7 Summary of LBC strategies and categories

Site/ Place Petal	Water Petal	Energy Petal	Materials petal	Health& Happiness	Equity Petal	Beauty Petal
Proper site surveying and understanding of surroundings and ecology.	Site rainwater and surface run off harvesting and recycling.	Net Positive energy strategy, no mains power supply (except in emergencies or resource deprived regions)	Waste produced in operation or construction must be recyclable or reusable with a minimal draft for disposal.	Create a biophillic site-connected environment indoors and outdoors.	Accessible and sociable design.	Aesthetically pleasing design.
Usage of table in appendix to calculate amount of farmable land per site.*	Maintain storage and treatment facilities for water and water reuse.	Electrical resilience, enforcing an energy storage system of 105% capacity.	Calculation of embodied carbon, by compensating for carbon produced during construction, by use of minimal emission systems.	Design of spaces encouraging social interaction	Pedestrian and walkable community design	Functionally assistive design.
Account for ecological value and arrange for rehabilitation or replacement of destroyed ecosystem	Net Positive Water strategy, No water is obtained from mains supply.	All electrical and energy generation is produced on site from non-combustible sources.	Proper and low carbon/ emission sourcing of materials.	Design of interior environments which are thermally, acoustically and visually comfortable.	Access to nature, parks and open spaces.	Educational imperative demanding allowance of visitors to tour and learn the strategies implemented in a LBC project.
Account for pedestrian transportation and vehicle/ vehicle pollution-free community.			Prioritizing local import of materials over long distance by penalizing the further the source is.		Human treatment of occupants in addition to a research-oriented donation as percentage of cost.	
			Sourcing of materials on a cradle to cradle system and by use of recyclables			
			Prohibiting use of Red List materials.			


Waste
Health & WellBeing
Materials
Energy
Site & place
Equity
Water

Chapter 4. Analyzing the PassivHaus (Passive House) Certification

The Following chapter will critically analyze and summarize the criteria, challenges and precautions needed, as well as the procedure to qualify for a Passivhaus certification and create a sustainable, low energy building

4.1. Context within Thesis

PassivHaus -as called in its country of origin- meaning Passive House, is the second certification scheme being discussed in this project. Being categorized previously in chapter 2.1.2.1 as a Cumulative Energy demand system, PassivHaus has a rigid list of criteria assigned that need to be met using passive design, PassivHaus approved merchandise and high recovery ventilation systems, proposed to achieve values almost 50% less than achieved through UK building regulations (NHBC Foundation and BRE, 2012)., thus by extension 50% less than achievable by BREEAM code three buildings. However a PassivHaus building is also capable of achieving a CfSH code level 4, due to the PassivHaus restriction that does not permit micro-generation (Permarock, 2013). In the larger context, PassivHaus as a certificate stands to hinder the development of this project. Thus PassivHaus' criteria will be reviewed during this section of the research solely for the means of understanding the methods to achieve the successful low energy demand reported by Passive houses. This research, as previously mentioned is not interested into rating the systems, merely critically analyzing their merits to extrapolate a larger more comprehensive set of criteria for sustainable design, the values discussed in PassivHaus will be lay the foundations for the minimal energy use criterion that contributes to the comprehensive outcome of this document.

4.2. Background

PassivHaus is a cooperation between German and Austrian efforts, created and advertised to be a rigid, cost efficient, energy efficient and comfortable sustainable building standard, it's awarded by fulfilling a list of requirements and is awarded by the monitoring and skillful application of its value, from inception, design to construction, finishing and monitoring after start of occupancy. The standard was under development in the late 1980s after the outcry against climate change, and was launched in early 1990s, marked by the first passive house constructed in 1991 (PHI, 2014).

The official definition of the standard, emphasizes on the standard's aim for comfort rather than being a simply energy tool, it adopts the notion that comfortable living should not come on the expense of energy expenditure, the exact definition quotes:

> *"A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air."* (PassivhausPlanner, 2015)

The standard references ISO 7730, in Great Britain also coded as BS EN ISO 7730, the code defining thermal comfort as the state of mind in which the user is satisfied with the thermal environment.

Utilizing the predicted mean vote (PMV) and Predicted percentage of dissatisfied (PPD) in relation to the local thermal environmental to calculate the thermal conditions required for comfort. The method ensures a comfortable thermal environment during the period of highest load while keeping any mechanical and optimization systems optimal and efficient as to provide the exact amount of fresh heated or cooled air at the lowest energy cost. In addition, the definition adopts the notion of maintaining indoor air quality. Whilst the concept of air tight design might enforce the assumption that the building does not acquire fresh air, or that the building does not need natural ventilation, it is however not the case, the standard enforces passive ventilation design which is embedded within an airtight fabric, minimizing losses and contributing to the building's overall thermal efficiency.
There are currently 50,000 (fifty thousand) passivhaus certified buildings worldwide (Passipedia, 2014), a figure that stands to increase with the consideration of implementing passivhaus strategies into the 2016 carbon target.

4.3. The Five Principles of PassivHaus

PassivHaus simplifies its requirements into five basic principles, ones if followed and accounted for during the design and manufacturing phase, would create a PassivHaus approved building, in other words, a thermally tight and efficient building. These principles have been summarized as follows:

Table 8. Summarizing the 5 main principles of PassivHaus design

<table>
<tr><td colspan="2">1.Air Tightness</td><td colspan="2">2.PassivHaus Certified Windows</td><td colspan="2">3.Heat Recovery Ventilation</td></tr>
<tr><td colspan="3">4.Thermal Bridge free design</td><td colspan="3">5.Thermal Insulation</td></tr>
</table>

The nature of these principles are a mixture between scientific methodology in determining the appropriate materials, thermal properties and heat loads of the building through calculation and simulations. In addition to consultancy with mechanical engineers or retailers specializing in determining the efficiency of the heat recovery system, and finally a skilled building crew, trained and capable of finishing the construction, insulation and finishing tasks up to code and without causing the loss of valuable material.
PassivHaus is claimed to be applicable to any climate (Schnieders et al., 2011), however its current mode of application within European countries of colder climates generates a focus on certain terms such as "heat use" and "heat loss", whilst in warmer climates it would be used to note "energy used and

lost", the energy used to cool the building rather. Its use is increasing in order to cope with rising energy prices and 2016 carbon target (Lane, Nialki, and Petrov, 2013)

PassivHaus guides stress on the fact that the standard has to be applied since inception, from the very start of the design process and all through the building's life till it reaches construction and occupancy (Cotterell and Dadeby, 2012). Despite the claims, the design phase of constructing a PassivHaus building is limited to the data it provides, it simply gives insight into the building's energy use and what is to be expected. However the larger responsibility lies within the installation and construction stage of that project.

The PassivHaus guide assigns a checklist through the different stages of building construction, some of which can be categorized as quality assurance and product testing.

The standard strictly relies on achievement of its four main criteria to grant its certification, these criteria are fixed and are required for certification no matter where the building is located. Since the main focus of PassivHaus is energy efficiency, it strictly relies on a fabric-first approach to achieve it. It relies on a strict air-tightness value, which allows for complete control of building's heating and cooling by using mechanical heat exchange systems or opening windows for ventilation during warmer seasons.

The researcher believes that such standardization of criteria despite location and climate type shows the robust algorithm and calculations of the PassivHaus tools, namely the PassivHaus Planning Package, which by switching values between heating and cooling loads (Cotterell and Dadeby, 2012)., would still provide the designer with the peak energy load, and thus provide accurate energy data for future or less climate severe scenarios (McLeod, Hopfe, and Rezgui, 2012).

4.4. PassivHaus Critera compared to current state in the UK

The standard's criteria have not changed drastically since its inception, however the current housing stock has been analyzed by different institutions such as BRE (Stephen, 1998) and Inspire (Birchall. et al., 2014), and the results produced given the age of dwellings in the UK have been less than efficient. The term described for most UK housing is that it is "leaky". Lack of appropriate air tightness control, the draught produced into the house provided more than enough ventilation needed in addition to siphoning the heat produced by different systems at place, traditionally open fires and more recently, that of central heating systems, heater fans or coils.

On the other hand, after the inception of BREEAM, and the creation of standards such as Eco-Homes, which has been optional through its existence, the UK government took an interest in creating more efficient homes by creating environmental criteria since Building Regulations 2000 that have been updated repeatedly over the years. Up until 2010 where it took up BREEAM Code for Sustainable Homes into its regulations, making code level 3 the minimum requirement for new dwellings. Presented is a comparison extracted from up to date reports and documents, as well as compared with official regulation manuals comparing the current status of PassivHaus alongside the efficiency of UK Building Regulations and the current housing stock's condition as shown in table .

Table 9 Table comparing PassivHaus, UK BR, and housing stock in performance

Requirement	PassivHaus Criterion	UK Building Regulations Criterion	Current UK housing stock data
Air Tightness	Below **0.6 air changes per hour**.	0.5-1.0 air change/hour at 0Pa, averaging to 10 air changes/hour at 50Pa (CIBSE B2, 2004), 3-4 required for toilets and kitchens (Building Regulations, 2010).	Current UK stock has an air change rate of higher than 10 ach, the information while aged, still stand (Stephen, 1998).
Annual Space Heating or Cooling Demand (kWh/m2 per annum)	A standard fixed value of **15kWh/m2.a** is required to heat a space above 20 C for thermal comfort or to cool buildings below 25 C	There are no regulations bluntly stated in the UK building code. However since 2010, the implementation of BREEAM CfSH code three into building regulations, by the extension the current values should stand at 43-52 kWh/m2.a	An independent report in 2014 shows an average use of 153 kWh/m2.a within the UK. While the sample includes different types of dwellings such as multi-family complexes, it does however include an 89% abundance of single family houses, thus the figures stay valid. (Birchall. et al., 2014)
Specific heat load W/m2	Criteria demands **10W/m^2** to maintain 20C inside the building at -10 C outside $\Delta T = 30$	None stated, calculated whilst applying mechanical heating or cooling systems.	No data recorded.
Annual Primary Energy Demand kWh/m2.a	The total amount of energy needed at source to generate the different forms of energy required to operate the dwelling : **120kWh/m2.a,** this criterion is enforced in all cases.	No data recorded per dwelling. Values are inclusive of all types of dwellings in million ton equivalent of oil, and conversion will not be viable.	Over 300 kWh/m2.a (Butera, 2010)

4.5. Use of PassivHaus Planning Package (PHPP)

The PHPP is a design tool used by the passivhaus designer, or the passivhaus accredited architect in order to optimize the build's performance. This stage takes place after the architect's design is created and the optimization process starts. It eliminates the need for blind assumption by adopting a sophisticated mathematical tool to apply a large set of values required to accurately estimate the building's heating, cooling and energy loads. Allowing room for manipulation, area changes and acquiring of u-value appropriate materials, windows, openings and sealants for an airtight structure.

The PHPP datasheets requires specific information in order to maintain an accurate estimation of energy loads, the amount of values required while much larger than that required by SAP, provides an accurate representation of energy estimates for the building upon completion. Some of the key work sheets in the package are listed as follows in table 10:

Table 10 Description of the sheets included within the PHPP

Sheet Title	Sheet description
Verification	This sheet contains the summarized information after input of all the values into the other worksheets. In addition, it calculates internal heat gains by deriving estimates from the number of estimates and floor area occupied per occupant at an estimate of $35m^2$/person
Areas/Treated Floor Area (TFA)	This worksheet required the external dimensions of the building and its envelop, the calculations made will be used to determine irradiation rates, treated areas, etc
Thermal Bridges	The length of thermal bridges and their Psi has to be mentioned in this segment in order to modify the model for accuracy
U-Values/U-List	U-Values page contains a detailed list of each element of the fabric, it's components, thickness and u-value. The algorithm then adds the values to determine the thermal conductivity of the fabric, and creates a summary/list of the elements on the U-List sheet.
Ground Sheet	This page creates calculates losses of building's heat to the ground. If not mentioned, the algorithm will assign standard values and assumptions that are applicable to most UK buildings.

WinType	Includes a list of the different window installations that will be applied to the building, containing the U-Values of the glazing, frame, the type of glazing, thickness and other details needed to calculate solar gain through openings.
Windows Worksheet	This sheet utilizes information gathered from the areas sheet to determine the fabric member, manual input of the window openings as well as information from WinType sheet to insert the technical data associated with the window type and the glazing information associated (g-value and Ug-Values). The sheet also includes orientation, deviation from north, angle of inclination, window areas as well as distance and connection to walls or other windows.
Shading	This work sheet tackles a specific issue that hinders proper solar gains during winter demand season. Shading causes a reduction in solar heat gains incident on the building's fabric and through its windows, thus by calculating the effect a more appropriate model can be extrapolated to compensate for these reductions.
Ventilation	The ventilation worksheet assists with an accurate assumption for the building's ventilation system, the mechanical ventilation heat recovery system (MVHR). It uses the number of occupants, and area per occupant inserted to calculate the amount of fresh air and heat required, in addition to the extraction of stale air from damn areas such as kitchens and bathrooms to avoid buildup of contaminants and fungi on internal surfaces (Mensah-Attipoe et al., 2014).

4.6 Building Development Checklist

PassivHaus states that its standard is design oriented, all the decisions calculated and made during the design stage are responsible for the building's success or failure. The institute has created a checklist outlining the

i. Design and Development Stage

Table 11 Summarizing the Design and development stage

Site Usage	Solar Passive Design	Function Appropriate Design
• **Manage proper connectivity to and from the site,** • **Proper building orientation within the site to maximize solar gain** • **Compact design for maximum land use and allow the possibility of building extensions.**	• Use of proper shading ratios, or lack of if possible to maximize solar gain. • Shade-free vegetation • Maximize south facing openings to allow maximum solar gain and heating during winter. • Minimize North facing openings to reduce heat loss. • Allow options of minimal shading during the cold season, especially for south-facing facades to allow maximum solar heat gain. • Simplify heat-gaining surfaces of the envelope, while it is an appropriate option solar gain, it hinders aesthetic value.	• Using proper layout and functional design, keeping service ducts and connection distances to the minimum by overlapping services of the same type over multiple floors. • Complete insulation and isolation of basement levels if existent.

Design and development stage is summarized in including PassivHaus requirements within the architectural design phase, after which, data is input into the PHPP for energy calculations and optmisations and shown in table 11. The use of PHPP software to calculate the energy requirements and efficiency of the architect's design, in addition to the use of supporting tools and plugins that can be applied to 3D modelling programs such as sketch-up to insert the model information.

ii. PassivHaus quality assurance in Implementation of the Dwelling's Functional Elements

Following table summarizes the analysis and followup done during construction and post-construction phase to insure quality and optimum results.

Table 12 Summary of Quality Assurance procedure whilst building a Passive House

Building Structure	Ventilation System	Dwelling's Service Systems
• **Use of low thermal conductivity materials of U-values lower than 0.15 W/m2K. Optimally 0.1W/m2K.** • **Omitting thermal bridges through design and technical details. In addition to calculating any risk of bridging.** • **Use of PassivHaus approved windows, or ones that satisfy the glazing quality/ratio, air tight frame and protection as required by PassivHaus.** • **Ensuring the use of foaming adhesives and plasters to ensure airtight connections.**	• **Ducting:** Duct paths need to be properly situated, cold ducts placed externally to avoid internal heat loss from spaces to the ducts. Whilst warm ducts are to be embedded within the structure properly insulated. (Kragh et al., 1151,Thunberg, 1983) • **Heat Exchange Units**: Use of technically compatible and power-sufficient central units, or if possible, PassivHaus certified units. Heat recovery must be ≥ 75% and operating at <0.4 Wh/m^3 . • Heat exchangers optimum positions are either placed in the envelope or underground basements. • Heating coils for fine heat management must be placed within the envelope. • Acoustic and thermal insulation of the heating units is recommended for minimal interference with space heating and noise pollution. • Use of sub-soil heat exchange or geo-thermal systems to substitute or support the heating systems.	Plumbing: Ensuring hot water pipes are properly insulated inside the building's envelope. Use of water efficient taps for normal use. Use of water efficient machines and dishwashers. Smart installation and fitting as to prevent penetration of the building's airtight envelope.

Chapter 5. Understanding BREEAM Code for Sustainable Homes.

Following chapter will critically analyze and discuss the mandatory and thesis-relevant categories within the CfSH to achieve code level 6, according to the 2009 technical manual and documents published accordingly.

5.1 Introduction

BREEAM's code for sustainable homes was developed part of an outcry following the Stern review in 2004, which had accumulated recorded evidence of a rapid increase in Carbon Dioxide emissions following the industrial revolution (Stern, 2006, BRE, 2006), from 280ppm to 430 ppm (parts per million) of Carbon Dioxide (Sondergard, 2009), a 34.9% increase, and an estimated increase of up to 550 ppm as early as the year 2035 (Newell and Hall, 2008). These figures estimated in 2004 still stand valid by recent calculations and predictions performed by intuitions such as the InterGovernmental Panel on Climate Change (IPCC). The results of the Stern review caused a concern towards the economics of suppressing and countering climate change, by focusing on Carbon Dioxide emissions as a primary marker. Thus by introducing the BREEAM's CfSH (BREEAM and DCLG, 2010), an incremental change is introduced supporting sustainable home design, these increments are implemented and upgrades every few years, last in 2010 by implementing code 3 into UK building regulations. Next in 2016 with the rise of the new Zero Carbon target, which will sway the government towards implementing code level 4 into new dwellings. It's expected by taking this incremental approach that by 2050 a third of housing stock will meet sustainable criteria thus helping provide both comfortable dwellings whilst creating durable, sustainable and environmental structures.

The code also mandates performing an energy and carbon assessment, performed under the criteria of Energy performance Buildings Directive (EPBD), which issues an Energy Performance Certificate. The calculation methodology used in both the CfSH and EPBD are the same, being performed under Standard Assessment Procedure (SAP), thus there will be no need to perform the same task twice.

The introductory technical published 2006 for the code has set certain long term goals for the code's target in reducing emissions and sustainable practice, one of its goals was also to provide a way for developers and consumers to understand the quality of the dwelling put on the market, given the simpler rating system and the use of codes one to six, symbolized by one (★) to six (★ ★ ★ ★ ★ ★) stars, denominates the next step already treaded by the BRE, the announcement of the Home Quality Mark during Ecobuild 2015, and final release in October 2015.

5.2 Context within this Research

As previously mentioned, whilst this project does not focus on creating a comparison between the given systems, its main goal is to extract the most beneficial practices and criteria from each standard in order to contribute to a more holistic and comprehensive sustainable design. Thus by understanding the flagship sustainable assessment in the UK, the successor of EcoHomes (BRE, 2006) , the Code for Sustainable Homes, a more ideal set of criteria can be extracted that are more location specific to the UK. By retrospect, given the predominantly guidance oriented nature of the Living Building Challenge, and the Energy specific nature of PassivHaus, a set of defined numerical criteria need to be extrapolated in order to fill in the gaps and specifics not satisfied by the first two systems.

BREEAM Code for Sustainable Homes is a Total Quality Assessment system with a Carbon target ideology, it addresses all the aspects of building design and construction, it covers not just energy or carbon criteria, but it includes building services, waste and other criteria that will be further discussed and explained. By allowing from a range of targets to be met per criterion, starting from level 1, the minimum and up to code 6, and the highest. At the moment due to UK building regulations changed 2010, minimum required code to be achieved is code 3, thus narrowing the range. And as previously mentioned, code 4 will be possibly applied as a minimum as part of the new Zero Carbon target.

Thus to conclude, this chapter of the project will solely focus on the criteria that contribute to achieve codes five and six, given that the difference between both is a matter of 6 points, thus there will be no significant changes in most of the mandatory requirements. In addition, the research will explain the methods required to achieve the points required for each of these criteria to be able to complete a comparative analysis in the end as to which method in each system would be better capable of contributing to a holistic design.

5.3. Compliance and Critical Review of the BREEAM CfSH design criteria

The following section will critically and briefly analyze the different categories of the CfSH assessment system.

A.i Category Ene. Energy and Carbon Emissions

Table 13 Summary of criteria needed to achieve code level 6 in Ene. Category

Criterion	Code level 6 Compliance Requirement
Carbon Dioxide Emissions	Net Zero Carbon emissions are required to achieve code level 6
Fabric Energy Efficiency	• A compliance of 39 kWh/m^2/year for mid terrace, • And 46 kWh/m^2/year for end terrace, detached and semi-detached are required.
Energy Display Devices	The requirement of installing energy consumption (and production) monitoring devices in order to create awareness within the household.
Cloths Drying Space	Creating a space in which cloths drying can be done manually without the need for mechanical and energy consuming appliances.
Energy Rated Appliances	• A+ rating for refrigeration of food and • A rating for washing machines and dishwashers.
External Lighting	• Maximum Wattage of 150W, • Fitting of daylight and motion sensor cutoffs.
Energy Generation	Use of low/ zero carbon measures to generate supplementary energy to reduce emissions during operation. A reduction of 15% in CO_2 emissions is needed for compliance.

This section will present a summary of each category individually while analytically criticizing the ideology and methodology behind it in each corresponding discussion section, this will allow to draw a summarized conclusion at the end of this chapter as to which criteria would prove to be a beneficial addition to the holistic design criteria hoped to be produced by this project.

A.ii Discussion:

- **Carbon and Energy Calculations (SAP worksheet)**

Emissions are calculated using the SAP calculator, whilst similar to PHPP, it requires less information input and allows for the use of biofuel and combustion operated energy generation methods and accounts for emissions caused by heating appliances such as boilers, cookers, and ovens, it presents another dimension to radiant heat emitted within the fabric and the energy used to power the devices thus influencing the overall heating load and the carbon dioxide emissions. However while SAP allows for freedom of choice in choosing the insulation quality and supplementing with different heating systems as opposed to PHPP, it does allow for a less rigid system that promotes achieving an end result without larger concern for the means. In addition, the calculations are mainly based upon energy used for 1. Space heating and cooling, 2. Hot water provision and 3. Fixed Lighting.

Ene.1 Carbon Dioxide Emissions	**Net Zero Carbon emissions are required to achieve code level 6**
Ene.2 Fabric Energy Efficiency	• A compliance of 39 kWh/m^2/year for mid terrace, • And 46 kWh/m^2/year for end terrace, detached and semi-detached are required.

- **Benefits of Energy Display Devices**

Table 14 Energy Display Devices

Ene.3 Energy Display Devices	The requirement of installing energy consumption (and production) monitoring devices in order to create awareness within the household.

Whilst energy metering over the primary inlet has been performed to maintain electric bill pricing, it does not provide an adequate output for users to understand their consumption. Following a policy design between July 2010 and March 2011, as well as a long-term testing stage through optional schemes (DECC, 2015), mandatory installation will be enforced between 2016 to 2020, as part of an awareness approach aiming to target all of the social, behavioural, technical and policy related factors to energy consumption (Darby, 2008). However by focusing again on the CfSH's policy towards metering, it does not only advocate the use of smart metering for electric usage, but for energy directed towards space and water heating, two meters for two functions, or one meter if heating utilities are solely powered by electric sources.

External Lighting	• Maximum Wattage of 150W, • Fitting of daylight and motion sensor cutoffs.

- **Energy Efficient Lighting Systems**

While a seemingly simple concept, the usage of efficiently connected sensors can yield a reduction of 50 % - 70 % within a space (Delaney, O'Hare, and Ruzzelli, 2009), whilst paired with daylight sensors, the system can omit their operation during undesirable hours such as late nights or daytime.

- **Energy Generation through Micro-Generation or communal sharing.**

Given the ability and option to generate a portion of electricity or energy required for household

Energy Generation	Use of low/ zero carbon measures to generate supplementary energy to reduce emissions during operation. A **reduction of 15% in CO_2 emissions** is needed for compliance.

operation on site, a system that directly feeds into the project is to be placed. These systems often carry an extra initial cost, yet manage to cause overall savings on the long run. These systems' carbon impacts need to be compared opposite the mainstream energy's carbon impact supplying the house of 0.527 $kgCO_2/kWh$ (DEFRA, 2008, DEFRA, 2012, Carbon Independent, 2015). Some examples of such systems would be the use of sub-soil heat exchange, geothermal loops for heating energy substitutions, and the use of photovoltaic arrays for electric micro-generation. This cannot be scaled up to include grid and community generation, thus it limits the benefits to site-only generation hindering what can prove to be a larger opportunity for Carbon emissions reduction.

B.i. Category Wat: Water use

Upon reaching decisions on energy and carbon dioxide emissions, the second category that governs the use of water in-project and on-site. Through a number of systems, it essentially advocated the efficient use of potable water, and substituting it with recyclable sources, as well as conserving its use through fittings and appliances.

Wat1. Indoor Water Use	This criterion limits the daily use of mains potable water to ≤ 80l/person/day.
Wat2. External Water Use	The installation of an appropriately sized collection, treatment and storage system for grey and rain water to reduce the consumption of potable water for external site usage such as gardening.

B.ii. Discussion

The category's main focus is the absolute reduction of mains potable consumption through different means and to be maintained as low as possible. On average, a person uses 149 liters of water (or 54 meters cubed of water per day) in day to day activities (CCW, 2015) due to inefficient products and fixtures, high capacity toilets, extended shower and tap operation when not in use . However the use of efficient measures is not the only efficacious method to promote sustainable water use. As described by in a paper by Gilg, Barr and Ford, behavioural models proved that water use is mainly a matter of sound behaviour and sense of control by using what is necessary, not just the use of water efficient means. But a sense of perceived efficacy against the rest of the society, comparison of the user's consumption to others, thus ultimately a person that consumes water in a certain way, even if wasteful, is likely to be part of the larger public in his immediate surrounding society (Gilg, Barr, and Ford, 2005).

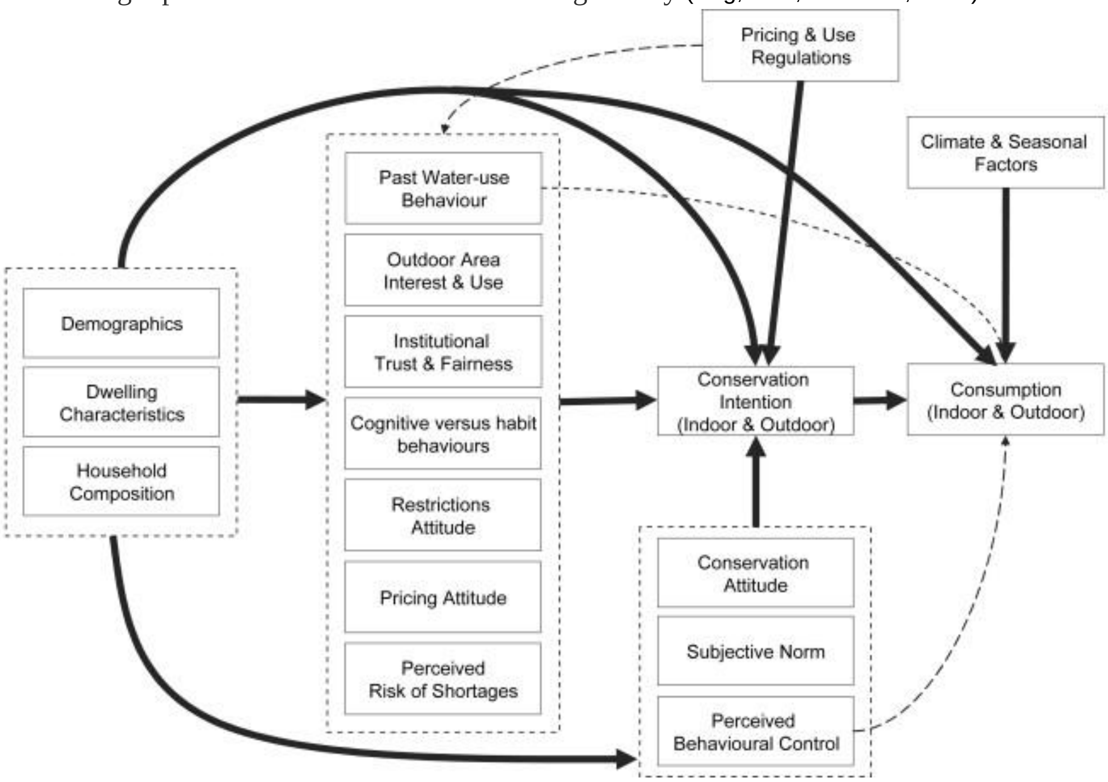


Figure 5 Diagram showing the complex process of influencing user behaviour (Jorgensen, Graymore, and O'Toole, 2009)

As shown by figure 5 extrapolated by Jorgensen, Graymore and O'Toole, the behavioural response of consumers to water efficiency measures and the alteration of their behavioural norms is interconnected with a much larger system of stimuli inflicting them, starting with decision/ policy makers to society and personal behaviour. And the influence of one stimulus without the rest can result in a counter effect in which consumers feel too restricted (Corral-Verdugo et al., 2002, Gregory and Di Leo, 2003).

C.i Category Mat, Materials' Impact and Sourcing

Material Impact Rating	Material impact rating is calculated on two levels, material environmental quality, given a grade from A+ to E. In addition the material's life cycle assessment, given its environmental impact as assessed on multiple levels to determine the product's category.
Material Sourcing	Requires the appropriate sourcing of materials used in the building's different structural and finishing elements of up to 80%. And the sourcing of wooden elements has to be 100% from legal sources.

C.ii. Discussion

The two criteria in this category are interrelated, since not only does material sourcing affect the material's environmental impact, but so does its mechanical properties and the methodology by which these materials were produced.

The calculation of material impacts is a sophisticated procedure, accounting for a large array of environmental elements and the effect that material has on its environment, in addition to its degree of longevity and survivability during the life cycle of a project.

The design elements in question are categorized and compiled to generate a database/ table of items that are to be used in the building, the list includes several categories;

- Frame
- Ground floor
- Upper floors
- Roof
- External walls
- Internal walls
- Foundation and subsoil structures
- Staircase,

All of which need to be modelled using the Code Mat 1 Calculator specified by the Green Guide (DCLG, 2010). The calculator uses a predefined algorithm using each material's environmental impact per building element to generate a rating from A+ to E, as well as its specific carbon impact (kg CO_2/m^2) (Mundy and BRE, 2015, BREEAM, 2013).

The calculator works on assigning EcoPoints to each material before grading it using the lettered system, each building type, according to location and wear stress is given a certain range of points accordingly (Mundy and BRE, 2015). These points determine if the materials are suitable for that specific type of construction or not. In the case of this thesis' focus, dwellings, which are assigned a total of points between 0 to 1, one being the lowest score for the dwellings category and thus given an E and is deemed unusable by BREEAM CfSH standards, the optimum points for structural elements in dwellings is 0.2 – 0.5, assigned points A+,A and B (Anderson and Shiers, 2002).

However the calculator does not stop at the previously mentioned step, the assessment methodology references the materials chosen through the calculator through its database, that database includes a plethora of materials' environmental impact of a number of markers. Each material can hold a score or effect in more than one marker, the weighting of these points ultimately combines to form the EcoPoint score of each material, added to give the score of the building element at question through a score or a fixed grade system.

Each material is assessed according to the danger and impact it causes its environment where it's extracted from and where it is to be installed, each substance can have an effect on more than one marker of the following list in table 15.

Table 15. Brief Description of the ecological criteria measured by Mat01 Calculator

1. Climate Change	**The global shift in weather planets caused by the different emissions and practices performed. Materials are assessed in this category according to their Carbon Footprint. Kg CO_2 equivalent. (Mundy and BRE, 2015 ,MetOffice et al., 2010)**
1 Water Extraction	The amount of water extracted and used in order to satisfy a consumer or used in the purification or creation of products used in construction. li
2 Mineral Resource Extraction	The impact created by the process of extracting virgin materials for manufacture and implementation, calculated in Kg/Ton material extracted.
3 Stratospheric Ozone Depletion	Damage caused by any gaseous releases caused by the materials used, gases that cause the depletion of the ozone layer and reduction of its protective benefits expressed in Kg CFC-11 equivalent. (BRE Green Guide, 2015)
4 Human Toxicity	Release of materials that have a negative impact on human health, causing a range of health issues from mild irritations to toxicity and fatalities.
5 Eco-toxicity to Freshwater and Land	Release of toxic material, waste, fluids or gases during manufacturing project or after implementation that would cause destructive effects to the environment.
6 Waste Disposal	This category detects the amount of resource wasted by disposal or incineration, it however doesn't account for recycling of materials or the emissions, both toxic and climatic (CO2) released from its decomposition or incineration.
7 Fossil Fuel Depletion	A marker that addresses the use of fossil fuels that are consumed during the production, transport and installation of a product, as well as the impact.
8 Eutrophication	The excessive use of ammoniate and nitrate chemicals, deplete the soil's mineral, and can cause toxic effects in water surfaces leading to loss of biodiversity and toxicity to consumers and environment alike. (Gerilla, Teknomo, and Hokao, 2007)

In conclusion, the methodology adopted by the Code Mat 1/ 2 Calculators perform a thorough assessment of materials environmental impact, they calculate the materials carbon emission factors, their multiple environmental risks and assign a simple alphabetic grade as a simple faced tool utilizing a highly sophisticated method.

It seems clear that the Code Mat 1/ 2 calculators are essential tools for any holistic sustainable design, no matter its certification scheme, weather employed by a BREEAM certification or any system of sustainable construction and design assessment.

5.4 Summary of Categories covered by BREEAM's Code for Sustainable Homes.

BREEAM as it was established in section 5.2, is a Total Quality Assessment system, covering a range of categories that contribute to a holistic standpoint. There are a total of 9 categories, each contain a number of criteria that need to be met in order to achieve a certain code rating. There are 107 points in total, 90 are required to achieve code rating of level 6. However the specifics on the rating scores and weighing will not be mentioned in detail in the body of this thesis project, but will be added as supplementary material in appendix.

Table 16 Brief of all criteria covered by CfSH

Category	Criteria Encompassed Under Each Category
Energy and CO_2 Emissions	• Dwellings Carbon Dioxide Emissions Rate during operation and occupation. • Fabric Energy Efficiency, relatable to Heating/ Cooling demand rate in PassivHaus • Energy display devices, • Cloths drying space to reduce reliance on tumble dryers, • Energy compliant appliances and white goods, • Energy saving and efficient lighting for zones outside the building, • Low and Zero Carbon methods of generating energy or electricity for project use, • Cycle friendly amenities for secure and sheltered storage • Design of an internal space capable suitable for office work.
Water	• Management of water use inside the dwelling, • Water use for site services and other systems.

Materials	• Material Sustainability rating according to durability and impact,
	• Appropriate and responsible sourcing of materials used in both the building's
	    ○ Main and structural Elements,
	    ○ Finishing products and coatings.

Water Surface Runoff	• Management and ensuring continuous and safe surface run-off to municipal drainage services, • Floor risk assessments and crisis resilient design.
Waste	• Appropriate storage and disposal routes for dwellings waste, both recyclable and non-recyclable. • Management, collection and proper disposal of construction materials and waste during construction and finishing stages. • Composting Facilities.
Pollution	• Global Warming Potential and risks associated with finishing and insulation materials. • Reduction of nitrous oxide NO_X emissions.
Health & Well-Being	• Proper daylighting and creating a healthy well lit indoor environment. • Reduction of noise pollution by ensuring proper acoustic insulation of rooms adjacent between project and neighbours. • Providing a properly designed private space for usage without external intrusions. • Compliance with the design outlines of Lifetime Homes organization.
Management	• User operation guide for home systems. • Sustainable management of construction sites, • Impact calculation and monitoring of the construction process. • Safety and security by professional authorities or contractors.
Ecology	• Site survey to determine the value of the site. • Ecological enhancement of the existing site condition, • Protection of the site’s features during pre-construction and construction phases. • Change through improvement or deterioration of site value between its state prior and after construction. • Ensuring efficient use of building’s footprint and materials.

Chapter 6: Case Studies

Phase 2 of the thesis project; as mentioned previously utilizes the cross-case analysis methodology to lay the previously mentioned literature within context, used as a tool to further clarify the application of each assessment system and standard within the construction and design context.

The layout of the following chapter is simple, each case study will be identified by location, name and a set of general information denoting its identity, the system it's accredited with and at what code level/ grade it resides.

Following the identification, a summary of the sustainable procedures followed and criteria met to reach that standard will be summarized, compared to the current state of its code ,critically analyzed and concluding by a personal criticism upon which elements have proved beneficial or hindering to the project.

The chapter concludes by comparing discussion results obtained during the literature review to the results concluded during this chapter.

Section 6.1: Living Building Challenge Case Studies

Due to constraints related to finding a comprehensive example that represents a fully certified living dwelling, mostly related to projects being classified as private and thus kept off public record or the existing projects satisfying partial or older versions of the Living Building Challenge; it has been decided to include multiple examples which satisfy different partial requirements.

The Eco-Sense Residence, certified under version 1.3 was chosen as a metaphorical spearhead, since it embodies a family dwelling and some of the challenges faced to acquire certification. It has achieved Place, Water, Health, Beauty and process. And has failed to achieve materials petal due to inadequate carbon impact calculations.

The Project used to substitute for Energy petal, will be the zHome, a neighbourhood of townhouses built on a small footprint, as the design of a townhouse would suggest, and achieves a primary energy use that is 58% higher than PassivHaus standards, yet is 37% lower than average UK housing. This information is comparable thus, since both the United Kingdom and Washington state share a Cfb classification on the Köppen–Geiger climate system, an Oceanic or maritime temperate climate. However the building is certified in 2013, whilst version 2.1 of the certification was active, thus it is only a zero energy building, and not net positive.

Important note: As of the final submission date of this thesis project, there are no version 3.0 certified projects publicly announced. Primarily due to the fact that version 3.0 was only announced in 2015, and by accounting for design, construction, occupancy and an addition one year period of evaluation, it cannot be expected to exist before 2016.

6.1:A- Case study 1: Eco-Sense Residence

Eco-sense is the product of a family driven target to create a sustainable home capable of housing three generations of the owners' family on a permanent basis in addition to hosting a younger fourth generation. It is located in a cold climate region, the project has acquired Place, Health, Water, Beauty and Process petals, and due to certain climatic and documentation restrictions, have failed to acquire the energy and material petals despite satisfying a large portion of their requirements.

The following image shows the highly vernacular materials used in construction of this house, as well as basic case information provided in table 17.

Figure 6 Photograph of Ecosense House (Ecosense,2008)

Table 17 Case File summary (Living Future, 2008)

Item	**Information**	**Item**	**Information**
Status	Petal Certified Building	**Project Area**	232 meters squared, 2500 sq. foot
LBC Version	Version 1.3	**Building footprint**	167.2 meters squared, 1800 sq. foot.
Location	Victoria, British Columbia ,Canada	**Construction Start**	March, 2007
BioRegion	Cold North	**Occupancy Start**	December, 2008
Köppen-Geiger classification	Csb, Damp Oceanic Climate	**Occupancy**	Occupied by owners of the property, three generation family
Living Transect	L3 –Village or Campus Zone	**Number of Occupants**	Six occupants (6)
Typology	Detached House, Building	**Visitors**	40 tour visitors per month

Function	Residential, Home business, Education/ Research	**Operation of household**	Year-round occupancy and operation.

Site Petal

The project is constructed on a total site area of 7.5 acres, 30,351 m^2, two acres of which (8093 m^2) were an area of damaged earth, spoiled with landfill and effects of human use, in addition the land was barren, while whatever wasn't barren was full of damaging weeds.

The construction was performed on the damaged two acres to reduce any negative environmental impact. Furthermore, to reduce the effects of heavy construction, the need to excavate for piles and foundations, the architect designed the building accordingly with the form of an existing bedrock to accommodate for the residence, and some of the project's buildings oriented towards human activities, storage and certain animal- raising practices.

Discussion:

As the strategies have briefly mentioned, the owners elected to choose a site that was not zoned for residential use, a large brown field that remained damaged in one area and ecologically threatened in the remained.

The owners restricted intrusive construction to the damaged 2 acres of the site in order to nullify its negative impact, while an ecological exchange committee participated in conservation of the site's remaining area. By improving, enhancing and nurturing growth, the ecological region has been enhanced. The effects of ecological enhancement can, of course, be measured using different markers such as number of species per area, or rate of growth through certified environmentalists' services.

Summary:

- **Rehabilitation and construction on damaged land.**
- **Environmental rehabilitation and habitat conservation.**
- **Dedication of appropriate farm land for food production.**
- **Raising own animals for protein and dairy.**
- **Use of land's natural foundations for construction.**

Water Petal

Annual Water Use	Volume Harvested	Water Cistern Size	Grey Water
94.9 m^3	175 m^3	45.5 m^3	94.9 m^3

Collection Strategies:

- On- Site deep water well.
- Rain water harvesting and storage.

Conservation Strategies:

- An intelligent approach to water conservation has been used, a way of enforcing sustainable results, a system where water is conserved even if with behavioural flaws, which are typically expected with the number of occupants, and the presence of children in the household**. By reducing the diameter of water supply piping into different fittings**, water use is ultimately reduced, since you cannot waste what has not been used yet.
- The use of a **flush-ready compost toilet**, a system that when created has not been widely used, but currently marketed as the 1 Pint- flush toilet, using only 0.57 liters of water to flush and leading to a composting bin for odour elimination and providing compost for gardening needs.
- **Reducing the capacity of grey water delivery systems** feeding the gardens to reduce water use for irrigation use.
- **Resilience in design,** dedication of an oversized tank to provide water during possible 5 month drought periods, which is 46% of annual use, and 26% of collected volume as opposed to 5% recommended for economic, health and safety reasons (RIBA, 2000).
- Use of **fresh ground water supply for ingestion and indoor use** to reduce carbon and energy impact required by filtration systems for rainwater harvesting systems.

Summary:

By appropriate comparison to UK climate zones, the abundance of rainwater and ground water supplies allows for over-achieving in the water petal, even given this version (1.2) being outdated, the project still achieved both the resilience and net positive components required by version 3.0 of the system.

Energy Petal:

The project has not achieved the energy petal, due to the use of combustion systems for heating, but a short summary of the systems used will be provided to allow ground for future comparison.

- 12x Sharp 175 Photovoltaic Modules, totaling at 2000 Watts (2 kW).
- 800 ampere hour (ah) battery system for essential housing equipment and food storage
- 60 x Mazdon vacuum solar collection tubes, with a peak output calculated at 10kWh/year (SPF, 2010) at an average of 5.3hrs over a year long period (Current Results, 2015, LIC, 2015) . Due to the cold climate and northern latitude, the system would be rendered inefficient during winter periods where sun-lit hours are limited to 1.2 to 3 hours daily. (Current Results, 2015, LIC, 2015)

- Pyrolysis (Wood gasification boiler) of unspecified output. Does not burn the wood for energy thus is compatible with the LBC requirements. **However standard pyrolysis of wood or biomass produces an average of 2.22 kWh/kg of biomass at 50% moisture**. (McKendry, 2002)
- Propane boiler, a combustion based system, thus opting the building out of the energy petal, yet necessary to maintain heating supply and demand in the building.
- The house uses hydronic heating to reduce active heating load on the building, by using the heat of connective piping between different elements of the heating system and passing them through the building's outer fabric (Hauser, Kempkes, and Olesen, 2000).

Summary:

While the building did not meet a net zero target, and provided the harsh cold climatic conditions of the site, a more intricate use of air tightness and thermal insulation would have greatly reduced the heating load. However, the building's use of combustibles also violates codes of systems such as PassivHaus, which are focused on energy efficiency, given the large project area of the site, as opposed to the environmental impacts that would violate the place petal, a vertical or horizontal loop system as part of a ground heat exchange pump, with appropriate calculation, may have provided a more adequate replacement for propane burning. As well as the construction team's research has shown, introduction of an additional PV and solar heating array would have been more effective in covering the family's energy and electricity needs.

Materials Petal

Another unachieved petal, however reason for disqualification was not providing adequate carbon calculations from a professional third party assessor, thus the petal was not awarded. However a summary of material replacements required to avoid the red list has been provided, the materials used are of low carbon offset and do not contain toxic or noxious emissions or residue thus contribute to the health and welfare of users.

Table 18 Comparison between red list materials and safe alternatives used in Ecosense

Building Element	Red List Variable	Sustainable Replacement
Caulking	Various (silicon and plastics)	Clay
Paint	Noxious gases	Casein paint and lime plasters
Carpets	Various	No Carpets
Polyurethanes	Polyurethane	Hard/Natural Wax, linseed oil
Fiberglass insulation	Formaldehyde	Bespoke Formaldehyde free
PVC Piping	PVC	ABS/ HDPE connections
PVC Windows	PVC	Fiberglass frames
Lighting/ Thermostats	Mercury products	LED lighting, Compliant thermostats

6.1: B- zHome; Zero Energy Housing Petal

The zHome project has focused on and achieved the Place and Energy petals, thus this section will focus on the achievement of the energy component of the Living Building Challenge within a small urban context, one composed of a set of 10 attached townhouses, housing around 20 users. The project provides a system of communal energy generation and utilizes energy conservation strategies thus comparable to PassivHaus strategies yet results produced are far less efficient than that of PassiHaus.

Table 19 Case File Summary

Item	Information	Item	Information
Status	Energy Petal Certified	**Project Area**	1596 meters squared
LBC Version	Version 2.1	**Building footprint**	1245 m^2 total built area, 540 m^2 building cluster footprint. 54 m^2 per house.
Location	Issaquah, Washington	**Construction Start**	April, 2010
BioRegion	Cascadia	**Occupancy Start**	February, 2012
Köppen-Geiger classification	Csf, Oceanic Climate	**Occupancy**	Various families and individuals
Living Transect	L4 – General Urban Zone	**Number of Occupants**	20 occupants, fluctuating
Typology	Attached Townhouses	**Visitors**	4-5 visitors
Function	Residential, houses. Single unit used for education.	**Operation of household**	Year-round occupancy and operation for houses, intermittent operation for guide and tour center

This project was initiated using a design oriented, fabric and energy first basis, the architects set a number of design goals to be achieved, primarily the net zero energy strategy with minimal expenses, but also considering a number of other targets:

Constructability/ Standardized Design	Noise pollution reduction
Life Cycle Assessment and Impacts	Complexity and Maintainability
Future Flexibility for expansion and redesign	Health and Aversion from Toxic materials.

Building Envelope:

Building elements were constructed using energy efficient strategies, by using passive design, and insulating materials, a set of values were achieves for the thermal resistive properties of the building's fabric to achieve an air tight and energy efficient fabric to reduce space heating.

Table 20 Fabric Performance Values

Walls U-Value: 0.026	**Achieved using a timber frame, polystyrene and mineral wool insulation.**
Ceiling; U-Value: 0.016	Achieved by the use of a double SIP (standard insulation panel) membrane, filled using polystyrene and attached to a wood frame, whilst proper spacing of metal elements discontinued the thermal bridge.
Under Slab/ Ground Floor U-Value : 0.10	Expanded Polystyrene insulation.
Windows	Double Glazed argon filled panes with a fiberglass frame. Compared to triple glazed, the cost to benefit ratio was uneconomic.
Static Air Change Rate/ Air Infiltration Rate	ACH rate of 0.20 was achieved using a door test. However the tested pressure was not mentioned. Whilst ACH in purely heat-loss oriented manner is highly efficient, it is however only safe and healthy during non-operational hours.

Discussion:

- The values provided by the building's datasheets were in form of R-n, where n is the R- Value of said element/ material. To unify units in this thesis project, R- values were converted to U-Values using the equation U- Value = 1/ R- Value.
- The U- values achieved by the building's elements are of high thermal resistance, they are below the values required by passivhaus criteria in order to achieve an energy efficiency rate of 15 kWh/ m^2. Year.
- Air infiltration rate calculated does not mention the pressure it was calculated at, but given the static term, it is assumed it has been calculated at 4 Pa air pressure according to USA building regulations testing of 4 ach. Thus for sake of comparison, by proportionally calculating the change to 50 Pascals, zHome has an infiltration rate of 4 ACH (Fennell and Haehnel, 2005), which is alarmingly high compared to PassivHaus, CfSH and UK Building regulations requirements.
- Assumingly, the positive differential in ACH between PassivHaus, CfSH and the LBC is due to the use of non- airtight materials within the membrane, causing a high infiltration rate through the materials rather than through openings. Other possibilities would include a low standard of quality control and finishing during construction progress causing gaps through outlets and other fabric pores.

Conclusions regarding LBC strategies:

To summarize, the benefits and disadvantages of using the Living Building Challenge system do not lie only within the scheme's guidelines, but within appropriate and rigid design steps that govern the project as a whole. The strategies do not act as restrictions to inhibit or hinder creative process, but they serve a method of purifying and rooting out some of the unsustainable approaches used to achieve environmental design.

However, the Living Building Challenge provides adequate footing to incorporate the strategies and criteria recommended by systems such as the PassivHaus to achieve true energy efficiency. Whilst calculation tools, methods and criteria provided by BREEAM's Code for Sustainable Homes provide an accurate calculation for the environmental impact and energy emissions caused by materials, but only through averting from the restrictions and red list materials that endanger users' health.

6.2: BREEAM Case Study

The case study used for the BREEAM section is an ideal model project, formerly located in the BRE Innovation park in Watrford. The building was used as an example for a code 6 building as well as to provide hands on research to further develop the code. It has been decommissioned since then, to present an example for sustainable deconstruction.

6.2:A- Kingspan Lighthouse Building

Table 21 Case File Summary

Item	Information	Item	Information
Status	Code level 6 CfSH	**Project Area**	1596 meters squared
LBC Version	2006	**Building footprint**	1245 m^2 total built area, 540 m^2 building cluster footprint. 54 m^2 per house.
Location	Watford, Hertfordshire	**Completed**	2007
Living Transect	L3 – Village or campus Zone	**Occupancy**	Testing and office work
Köppen-Geiger classification	Csf, Oceanic Climate	**Current Status**	Demolished
Function	Residential, Office	**Occupants**	2 Bedrooms and Office

This project, sponsored by Kingspan, a manufacturer of building and finishing elements, and cooperating with BRE, was created as a model for a Zero Carbon, code level 6 compliant sustainable house in the BRE innovation park in Watford, its basic info is summarized in table 21.

The analytic segment of this analysis will pertain classifying the different strategies accommodated into their respective categories, in order to keep the case study's context compatible with the thesis' analytical structure. However since this installation was part of the BRE innovation park in Watford, UK, there are no immediate site strategies implemented, other than climatic, shading and orientation considerations. It is also notable that the building is funded by Kingspan, a company that specializes in construction materials and fittings, with a heading towards reducing carbon emissions, thus a number of building elements have been acquired through the company and are made to achieve a certain level of performance. A summary of criteria tackled by the design team are included in the following table

Table 22 Summary of Sustainable Strategies for Kingspan Lighthouse

Energy and CO_2	Water	Materials	Health & Well Being
Building Fabric	Rainwater Harvesting	Renewable Materials	Well-lit spaces
Thermal Massing	Gray water recycling	Low carbon Materials	Privacy
Air tight design			Work space
Electricity Generation			

Low impact heating			

Energy & CO2 Considerations

The design team's main objective was to reduce the building's energy demand through a fabric first approach, by using efficient materials and coupled with air tightness, rigid ventilation control, and resource use moderation. While the approach is significantly similar to PassivHaus, including the U-Value and the attempt to reduce the air infiltration levels, in order to reach the BREEAM certification, the design had to be performed through Standard Assessment Procedure (SAP) calculations.

The following table will summarize the strategies taken by the designers in order to achieve energy efficiency, however certain observations by the researched will be discussed following the table:

Use of high- performance brand certified insulation materials from Kingspan company of U-value 0.11 W/m2.K,
Use of phase-changing materials on the sun- facing roof to absorb heat during daytime and release during chilly night time.
Ensuring air-tight design by using appropriate sealants and non-porous materials, achieving 1 m3/hr/m2 at 50 Pa, equivalent to 1 ach at 50 Pa.
Use of a PV array to generate electricity for house use and to be returned to the grid.
Incorporating a biomass boiler for water heating needs within the building, as well as providing an alternative "hot room" for drying cloths instead of a tumble dryer.

The project attempted to achieve a higher score in the materials section, by aiming for sustainable sourcing of the Cherry Chestnut wood used for the building's cladding, known to be lighter and more durable than other types of wood.

The Kingspan elements materials are rated A+ according to the green guide, thus are expected to be sustainable and avoiding the LBC's Red List.

Furthermore, in terms of energy efficiency, while the building consumes an average of 80 kWh/m2/yr for all primary energy demand. Space heating requiring an average of 15.2 kWh/m2/yr, which is a mere 200 Wh/m2/yr higher than the PassivHaus requirement.

With regards to the other categories, the approach towards the project design was based on achieving subpar results whilst using conventional efficiency measures. In addition, while the approach for air tight fabric was an important step towards energy efficiency, the need for the use of combustibles would disqualify the project from receiving a Passivhaus and LBC certification. It is the researcher's opinion that the small floor area and tight spaces, the use of wood cladding in addition to the highly insulating Kingspan materials helped the project achieve its optimum results.

6.3: PassivHaus Case Study

PassivHaus case studies are fairly simple to understand, given the very limited targets needed to be fulfilled and the simple outline of methods needed to achieve them as mentioned in chapter 4. Thus this section will mention the criteria achieved by the Lancaster Cohousing project, due to a more comprehensive set of data being available. However the researcher had approached a firm responsible for design and post occupancy evaluation of housing project in Parsons Close, but due to certain discrepancies with the process such as malfunction with evaluation and metering tools, the information has not been used in the case study. But will be mentioned briefly and placed in the appendix.

6.3:A- Lancaster Co-Housing Project

This project was chosen specifically for a number of reasons, it encompasses a portion of this project that encourages the use of multiple assessment systems to improve design and efficiency results. Primarily, the project has achieved PassivHaus certification as well as Code for Sustainable House Code level 6, and Life Time homes, thus the building is both zero carbon and compliant beyond basic energy requirements. Secondly, the project is a part of housing scheme, creating a seemingly urban or village transect, allowing for community generation and benefits exchange between the units. Finally, the project has been occupied and tested since its construction has ended in 2012, it also is compliant with the 2009 technical specifications update for CfSH, as well as being allowed a year of post-occupancy evaluation for all of its certifications. Following table 23 will summarize the basic details of this project as provided by case file (PassivHaus Trust, 2014).

Table 23 Case File Summary for Lancaster CoHouse Project

Item	Information	Item	Information
Status	PassivHaus approved, Code level 6 CfSH	**Number**	41 Terraced Houses
Location	Halton, Lancaster	**Completed**	2012
Living Transect	L3 – Village or campus Zone	**Occupied**	Gradually since 2012
Occupancy	41 Owned occupied houses	**Available Occupancies**	Variable sizes between 1,2 & 3 bedrooms
Köppen-Geiger classification	Csf, Oceanic Climate	**Function**	Residential, Office

Like most PassivHaus projects, achieving the target values is heavily imbued within the design process, the PHPP phase and execution, thus a short summary of the efficiency values and simple strategies calculated during design and after design will be input into the following table 24 for summary and analysis :

Table 24: Values achieved and sustainable strategies used by Lancaster Cohousing project.

<table>
<tr><th>Category</th><th colspan="3">Summary/ Method of Achievment</th></tr>
<tr><td>Primary Energy Demand</td><td colspan="3">81 kWh/m2.a</td></tr>
<tr><td>Predicted Space Heating Demand</td><td>12 kWh/m2.a</td><td>Measured Space Heating Demand</td><td>13 kWh/m2.a</td></tr>
<tr><td>Heating Load</td><td colspan="3">9 W/ m2</td></tr>
<tr><td>Ventilation system</td><td colspan="3">Typical Paul Focus Mechanical heat Recovery Ventilation</td></tr>
<tr><td>Heating System</td><td colspan="3">Radiators in living spaces, fed by biomass boiler, and reinforced by solar and district heating</td></tr>
<tr><td>U- Values of building elements</td><td colspan="3">Short description of U-values within the building
Fabric Walls: 0.12 W/m2. K
Roof: 0.90 W.m2. K
Floor: 0.14 W/m2. K
Glazed openings (windows/doors): 0.89 W/m2. K</td></tr>
<tr><td>Water Heating Load</td><td colspan="3">26 kWh/m2.a</td></tr>
<tr><td>Electricity Use</td><td colspan="3">22 kWh /m2.a, supplied by a 50 kW PV array</td></tr>
<tr><td>District Water Heating</td><td colspan="3">• 40 kW Solar Heating Panels
• 150 kW Wood pellet/ chip boiler
• 5 cubic meter storage tank (5,000 liters)</td></tr>
<tr><td>Materials Use</td><td colspan="3">• Recycled Aggregate blocks with slag cement binder
• Responsibly sourced wood frames.
• Project is Carbon Neutral as calculated according to BREEAM Code for sustainable homes Mat01 Calculator.</td></tr>
<tr><td>Site and Community</td><td colspan="3">• Pedestrian community
• Shared car and bike park
• Shared pool and recreational facilities
• Shared laundry facilities.
• On-Site offices and workspaces</td></tr>
</table>

7.1 Case Study Comparison Results

In order to set a fair comparison between the case studies, the researcher has elected to choose a single criterion by which the comparison should be held, the one criterion that contributes in the average UK stock, contributes to an average of 53% (Communities and Local Government, 2006) or more of primary energy demand per dwelling, space heating. This criterion contributes essentially into building operation costs both financially and in terms of energy consumption. The use of primary energy demand or electricity did not seem to be a fair point of comparison since other factors, mainly behavioural; which tend to be erratic and variable between each dwelling, user and another, contribute into items such as water heating, lighting and power usage. Specific Annual Space heating is the measure of energy required in kWh to heat 1 m^2 of usable space, per year, given the unit kWh/m^2.a. Since the unit refers to a standardized unit over a fixed area, it would serve as an appropriate point of reference (Casals, 2006). As for other assessment criteria such as materials, water and waste, whilst essential to a holistic design, they are more lenient and flexible to accommodate in order to fit the energy model.

The three projects to be compared in this section will be as follows, the zHome; candidate for the Living Building Challenge, since the complex is a Net Zero certified Project with credible data provided through its website. And by default, given the lack of alternative in the case studies, Kingspan Lighthouse for BREEAM CfSH, and Lancaster CoHousing Project for PassivHaus.

Table 24 Case Stud Comparison

zHome	Kingspan Lighthouse	Lancaster CoHousing
Csf, Oceanic Climate	Csf, Oceanic Climate	Csf, Oceanic Climate
54.2 m^2 Footprint, 162 m^2 total floor area average.	9.6 m^2 footprint, 24 m^2 Total floor area	40.4 m^2 to 98.1 m^2 Total Floor area, footprint average 40 m^2
Heating Load: N/A	Heating Load: N/A	Heating Load: 9W/ m2
Space heating: 35 kWh/ m^2 .a	Space Heating: 15.2 kWh/m2.a	Space Heating: 13 kWh/m2/yr
• **Air tight design at 1 ach** • **Use of MVHR system** • **Hydronic space heating** • **Net zero energy achieved through substitution with generated energy by communal heating.**	• Thermal bridging at 4.5% of fabric. • Air tight design at 1 ach. • Use of MHRV systems. • Energy supplemented using biomass boilers and thermal mass.	• Single radiator per house. • PassivHaus Air tightness standards at 0.35 – 0.5 ach • Breaking thermal bridges and fabric design. • Highly thermal resistive insulation. • MVHR systems. • Energy use reduced

It is noticeable that PassivHaus has the highest efficiency rating between the 3 case studies in table , despite the efforts performed being similar with the exception of the ACH, there is a noticeable energy demand difference. However in order to understand the differences, a conclusive summary and analysis of the Energy component is to be concluded within this chapter.

7.2 Visualizing the Framework

"Buildings are living organisms. As soon as you finish them, they're bound to change." (Safdie, 2013)

Safdie's quote to NorthEastern magazine, voice of Northeastern University of Massachusetts, represents the fact that summarizes architectural design and construction. Sustainable architects and specialists strive to create tools that are capable of estimating and calculating accurate predictions for their incubated buildings and projects. However as shown through the PassivHaus case study, the results always include certain changes, due to behavioural, executional or other currently non-researched possibilities. Buildings are always evolving according to their quality, initial conditions, users and age. Which partially lies on sustainable design to create durable and consistent buildings.

However it is the researcher's point of view that not only buildings are living due to their evolving nature, but they are also living with regards to the categories that partake in their design. The main criteria of holistic design as deduced by the collective deductions in this research; energy efficiency, water, sustainable materials, site, pollution, equity and aesthetics. The aforementioned categories are in a way, the different elements that contribute to a building's wellbeing and by extension, the user's comfort and health. Metaphorically a building can be rather pictures as an ecosystem, with different elements influencing a single tree to produce a bountiful of fruit.

The figure opposite, provides a visual representation of how one can perceive the holistic sustainable design process. Simplified; Site is the place upon which the project is laid, which is to be tended to and protected. **Materials** determine the building's **durability** and how well it performs. **Water used reasonably** for heating or as potable water for daily needs and site management. The **energy** provided through different means, while not entirely similar to the sun, but the conveyed concept is similar, excess solar exposure would damage the tree, or in this case, damage the environment and negatively impact finances. The tree, or building, provides **shelter and gathering space** for users and community **(Equity & Society)**. All the elements above in the correct ratios and optimum performance will lead to a **fruitful impact on Health and Wellbeing**.

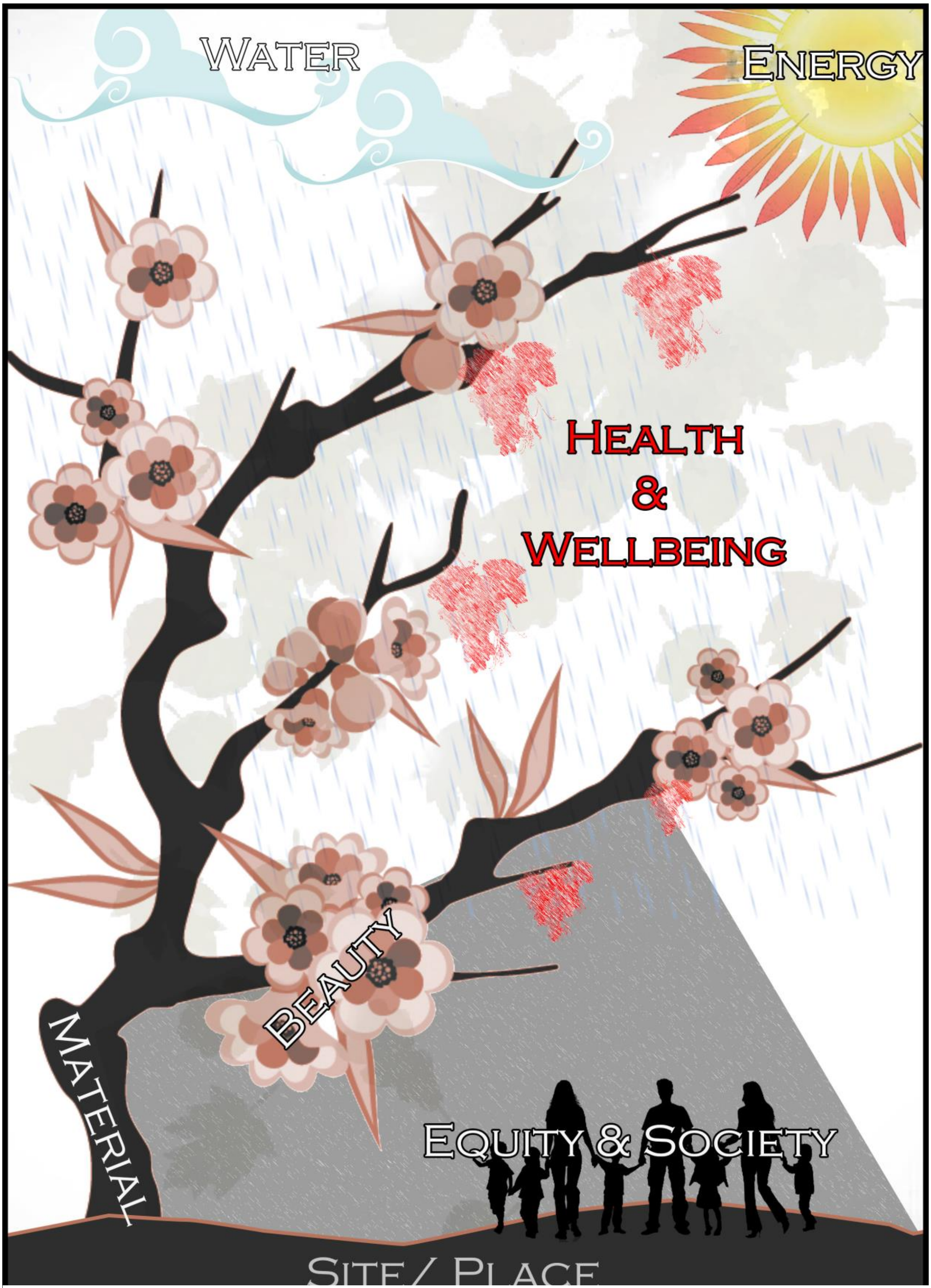


Figure 7 Visual Representation of Building as living organism

7.3 Components and Decisions

Upon concluding the analysis, the individual briefing of each assessment system, and nearing the conclusion of this thesis project, it is essential to start by drawing reason and conclusions from each individual section and case study, in order to piece together the optimum input required to maintain the previously mentioned, healthy tree. This section will start by stating the main consequential categories, the criteria proposed to be implemented under them and the reasoning as deduced by research and additional literature.

Site Component

The site component is by far one of the least regarded components within some of the assessment systems, whilst LBC dedicates an entire petal to site, site management, ecology and horticulture as a mandatory requirement, prerequisite to satisfying any other of the LBC's components, BREEAM CfSH's brief ecology, construction waste and management do not nearly cover nor provide enough guidance neither are they mandatory. The researcher finds the use of the site petal as a component for site criteria for any given sustainable dwelling, in addition to local rules and planning regulations, would serve as a viable option for sustainable site management in a step towards holistic design.

Energy Component

The current candidates for the energy component lie within either BREEAM and its SAP calculations or PassivHaus and PHPP calculations, however to decide which should be assigned the spot, the researcher must review upon the existing literature, case study and additional information.

By comparison of the criteria, PassivHaus has a rigid high limit regarding space heating and primary energy demand that should not be passed, and with the use of PHPP that limit cannot be crossed (Cotterell and Dadeby, 2012). Whilst BREEAM CfSH uses both a higher value range, and the use of SAP does not offer a failsafe in case the limits are crossed (BREEAM and DCLG, 2010).

However the difference between using SAP and PHPP lies further beyond the hard boundaries of end values, but within calculation methods themselves. During calculations, PHPP usually demands a higher energy value for space heating than SAP does (Moutzouri, 2011), due to a number of reasons. Primarily, PHPP has a strict definition as to the term of Total Floor Area, which can also be compared to the term Usable Floor Area, as to the spaces within the building that area large enough to require heating and are accessible/ useable by the occupant (Cotterell and Dadeby, 2012).

On the other hand, SAP takes into account more of the internal and incident heat gains within the building, which in an air tight building under PassivHaus' criteria, would reduce space heating demand drastically. However given the less strict nature of BREEAM, not requiring a building as air tight as PassivHaus, the values would eventually come close (Moutzouri, 2011). It is the researcher's remark though, that within a household, one cannot rely on the constant operation of electric, electronic, cooking or other equipment to satisfy those internal gains (SAP, 2012, Kingspan, 2008), not to mention the obvious electricity consumption, thus PHPP does seem to account for worst case scenarios, as it is easier and less energy consuming to open a window to account for heat buildup rather than generate heat to make up.

Thus to conclude, that whilst SAP calculations are applicable within a BREEAM context, this thesis project is not biased towards drawing criteria from one system or the other, but towards the criterion that would prove to be more efficient for a holistic design. Given the time and research input into designing PassivHaus and its PHPP, being an Energy Driven system by definition, the researcher has decided that the energy component of the design guidelines is **to be assessed by the use of PassivHaus methodology** in order to achieve maximum airtightness and accurate energy calculations.

Materials Impact and Life Cycle

While all the assessment tools support the concept of managing carbon emissions through the life cycle in the form of energy used to create, transport, and installation the building elements, in addition to energy used for energy and electricity. The LBC and BREEAM CfSH do call for material's environmental impact in their Materials component through two various means. The less sophisticated and thus less inclusive method, that of the LBC, requires the use of a carbon dioxide calculator through a number of online sources or through the use of a specialist. Whilst the accountability of carbon dioxide impact can be assessed through those methods, it however does not encompass the full range of material impact.

On the other hand, by the use of a simple tool provided by BRE, the Material Impact Calculator, the designer has to simply input the material code and other dimensional values in order to obtain a simplified grade by which the material is ranked, from A+ to E as explained in chapter 5. The use of this tool provides insight into more than the simple carbon output, but accounts to the impact done by its sourcing, transportation and fabrication. However the only visible downside given the calculator's algorithm, is that it hinders the process towards an optimum sustainable design, the calculator does not account for cradle to cradle possibilities, only cradle to gate or grave.

Given the fact that this research advocates the Zero Waste Policy proposed by the LBC, it is recommended by the researcher that whilst the material calculator can be a viable way to produce a user- friendly output into material rating. **An in-depth life cycle analysis performed by field specialists and thorough research would best serve the ultimate purpose of this thesis project's long term goals.**

Water Component

The water component faces no contradiction between one system and the other, both the LBC and CfSH require the water component to be satisfied. However by incorporating both criteria together, the Net positive water strategy of LBC and the 80 l/p/day quota of CfSH for comfortable yet sustainable living, and through thorough documentation and metering of harvested water, water used for daily activities, potable water for food and drinking. An implementation of both water criteria from both systems would ultimately lead to a drastic improvement in water use through the household.

Health and Wellbeing Component

This component closely operates with the energy component of any building. It advocates the users' access to proper daylight, ventilation and connection to nature in addition to a comfortable and livable interior space. However due to the restrictions and suggestions proposed by the PassivHaus guide, certain limitations when it comes to the visual aspect may come at play as mentioned in chapter 4, when it comes to limiting north facing openings, a restriction that may be overcome through intelligent architectural design to accommodate for both the energy requirement and maintain daylighting and visual continuity. Ventilation on the other hand is heavily accounted for by PassivHaus, not only does the MVHR system constantly renew air within a space, but access to operable windows gives the user freedom of controlling their space.

Waste Component

The final component to be discussed pertains to waste, inclusive to waste throughout the building's life cycle, starting by incorporating recycled materials into construction, to waste produced during operation and the waste produced after deconstruction or demolition. The LBC advocates a net positive waste policy where none is actually "wasted" (Cole, 2014). Organic material suitable for composting is used for that purpose and agriculture and recyclable materials are use and reused within the building and after decommissions. While BREEAM requires access to waste disposal**, LBC advocates on-site handling of waste when possible thus providing minimal output towards landfill**.

7.2 Conclusions

This research concludes by recognizing the effort and research input into the 3 assessment systems, and by implementing the stronger point of each, a simple layout of guidelines can be drafted in order to allow for further research.

All the systems complement one another, given the change in methodology, different results can be obtained, however since this project emphasized on laying groundwork for further optimization of holistic design, through cross-case analysis and literature review from official guidelines and additional resources, the researcher elected to choose certain points to impose into the set of guidelines to conclude this research.

To summarize, a series of diagrams have been created over the following 3 pages. Starting by the base image on page and imposed by two transparent sheets encompassing the input from each assessment system into this simplified and first step towards creation of a framework for holistic design.
The diagrams are represented by flowers, since mentioned before, the use of LBC analogy as a base print for the thesis project's components. Imposed by input provided by BREEAM strategies in green, and finally the PassivHaus input on top in red.

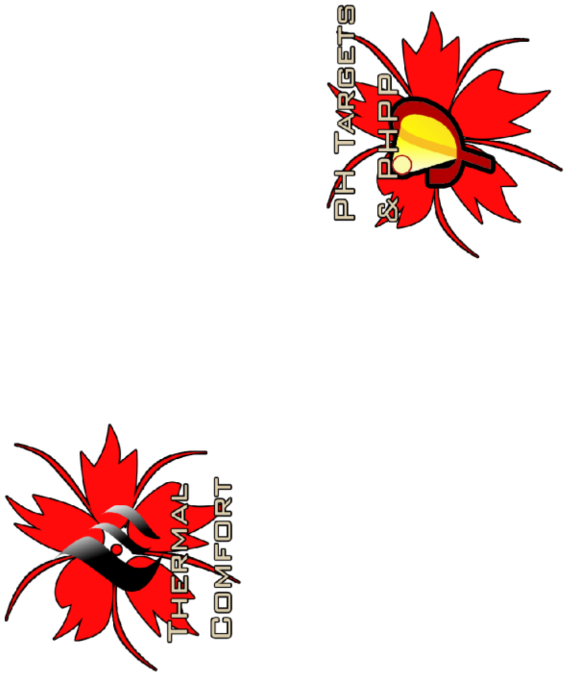


Figure 8 Transulecnt image of passivhouse flowers

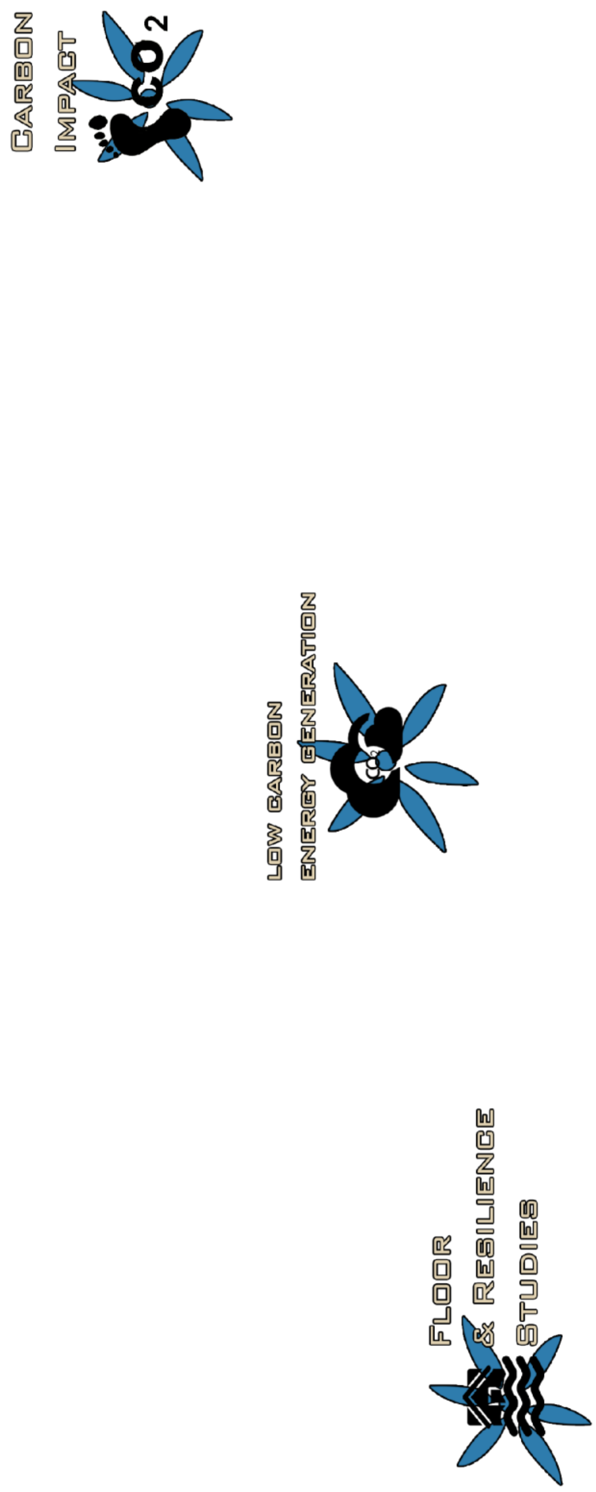


Figure 9 Translucent image of BREEAM Flowers

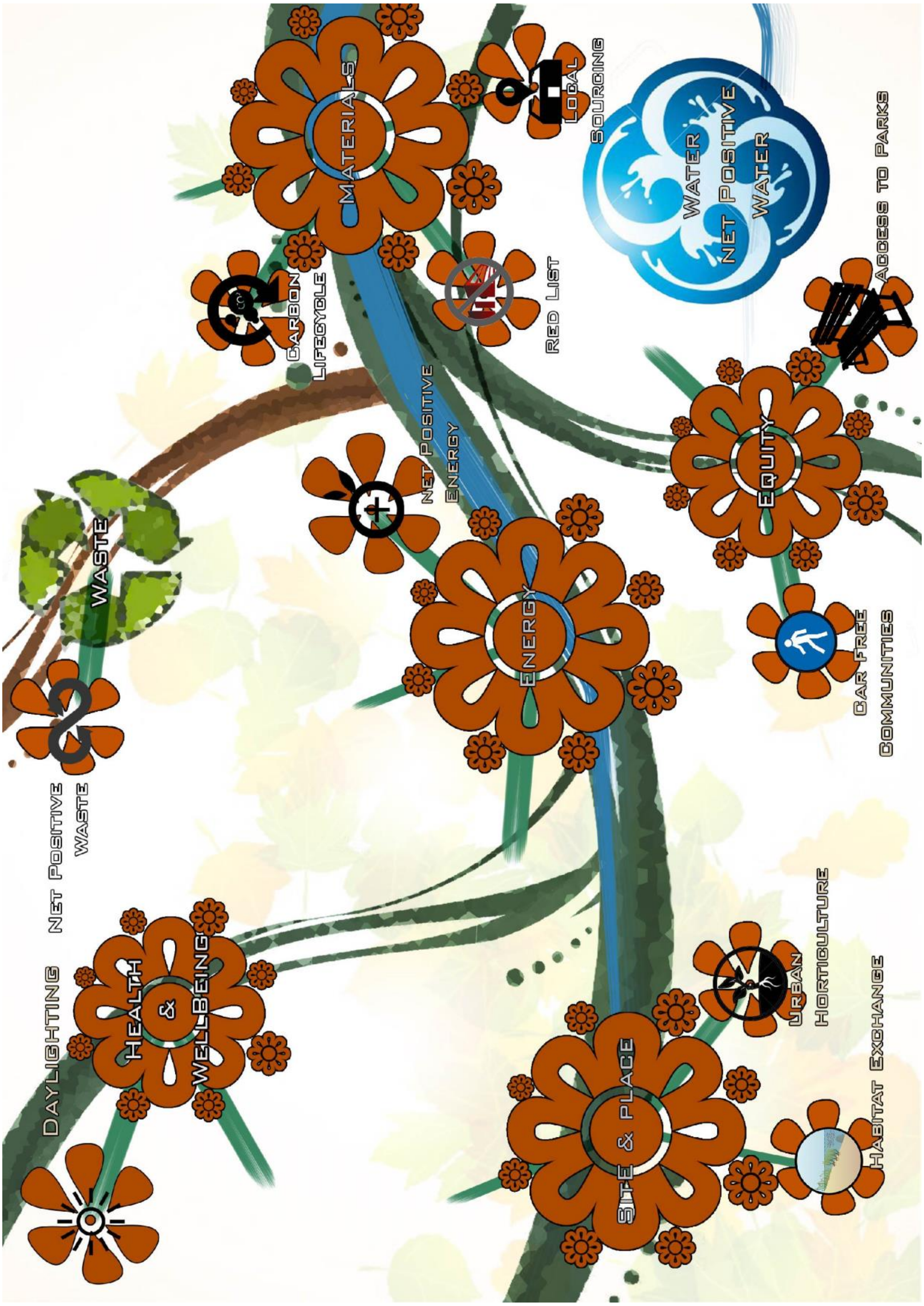
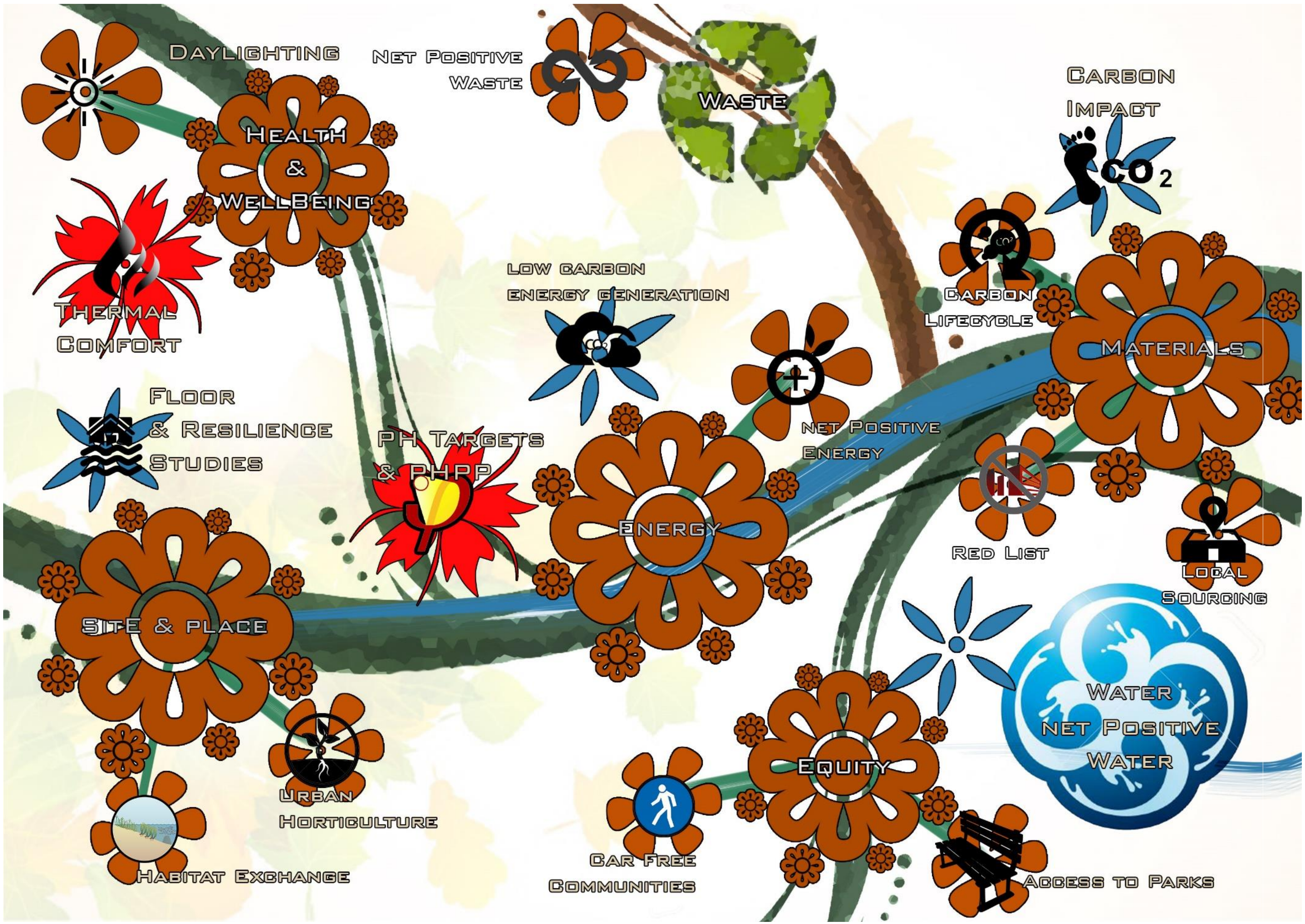


Figure 10 Back Image with LBC Flowers


Daylighting
Health & WellBeing
Thermal Comfort
Floor & Resilience Studies
Site & place
Urban Horticulture
Habitat Exchange
PH Targets & PHPP
Net Positive Waste
Waste
low carbon energy generation
Energy
Net Positive Energy
Car Free Communities
Equity
Access to Parks
Carbon Impact
Carbon Lifecycle
Materials
Red List
Local Sourcing
Water Net Positive Water

7.4 Recommendations for Further Study

This research limited by a short time frame, and limited access to resources and field research can only provide a compilation conclusions and results based on critically analyzed literature and cross-case analysis of case studies and assessment systems. However through further research, by implementing and analyzing the different guidelines proposed in this research, through field observation, digital calculation and simulation, a more comprehensive and holistic assessment system can be extrapolated.

Some tools within this research can be improved in order to provide better access to information and detailed analysis such as the BRE Material Calculator. By infusing concepts such as cradle to cradle design into the calculator's algorithm, by providing more access to carbon and impact data for various materials, or giving freedom to add those materials personally specially for innovative, recycled and site-mixed solutions for low impact construction.

Further research into horticulture and urban agriculture needs to be performed in order to satisfy the urban agriculture component in LBC, current solutions are not space efficient nor are they able to provide for families year long, in addition to the weight of the systems currently capable of holding them.

Finally, the researcher hopes and believes that research such as this and other scholarly input from different sources, can be integrated into a large set of possibilities, solutions and hurdles to be overcome through practical, thorough, scientific and empirical research in the future. All headed down a long road towards a true sustainable and holistic design, free from commercial shackles (Hahn, 2008), and both malleable and flexible to be shaped using creative architectural design, all focused for user comfort and satisfaction, and ultimately towards detaining the negative impact of the housing sector on climate change.

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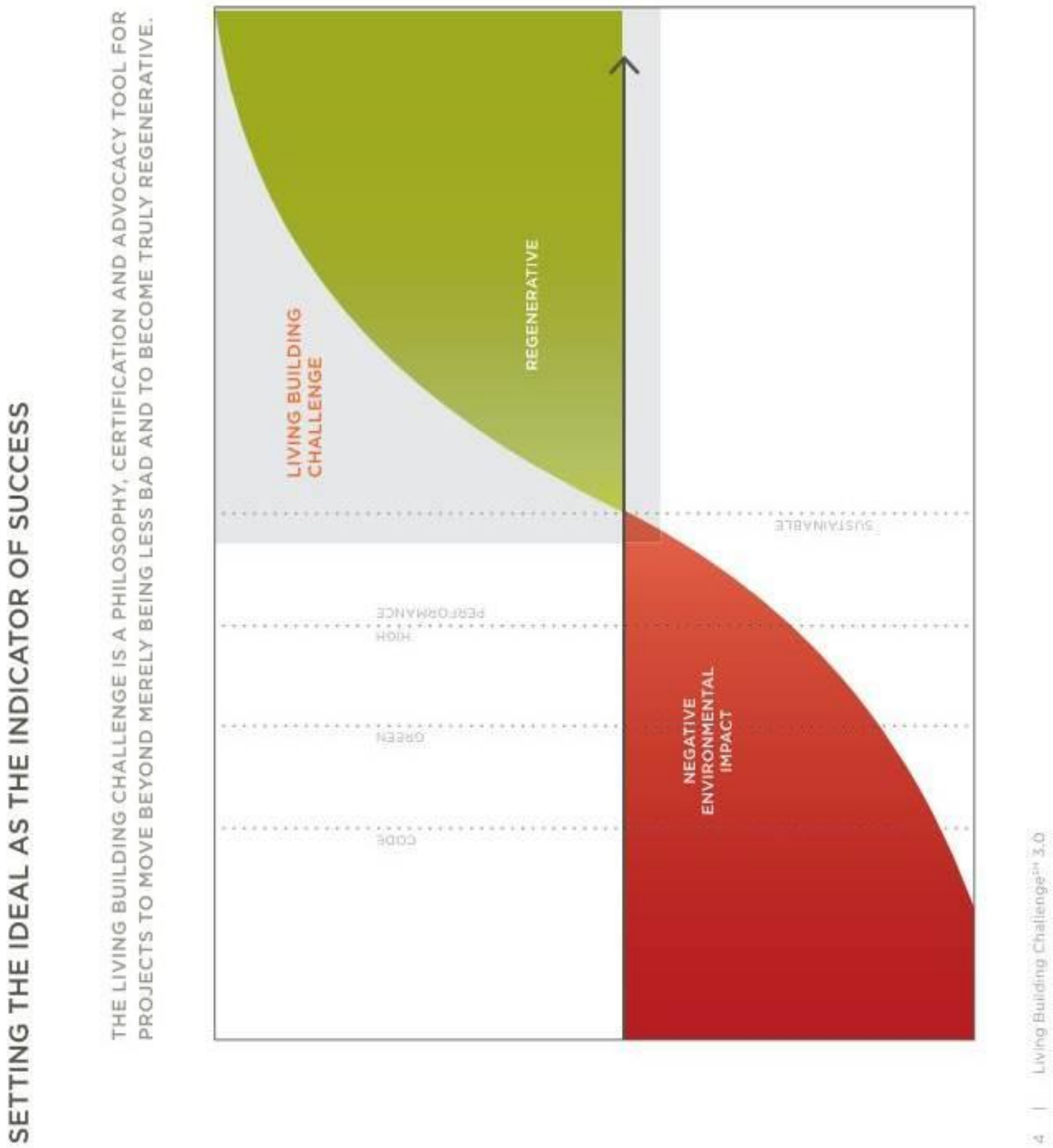
9.List of Tables

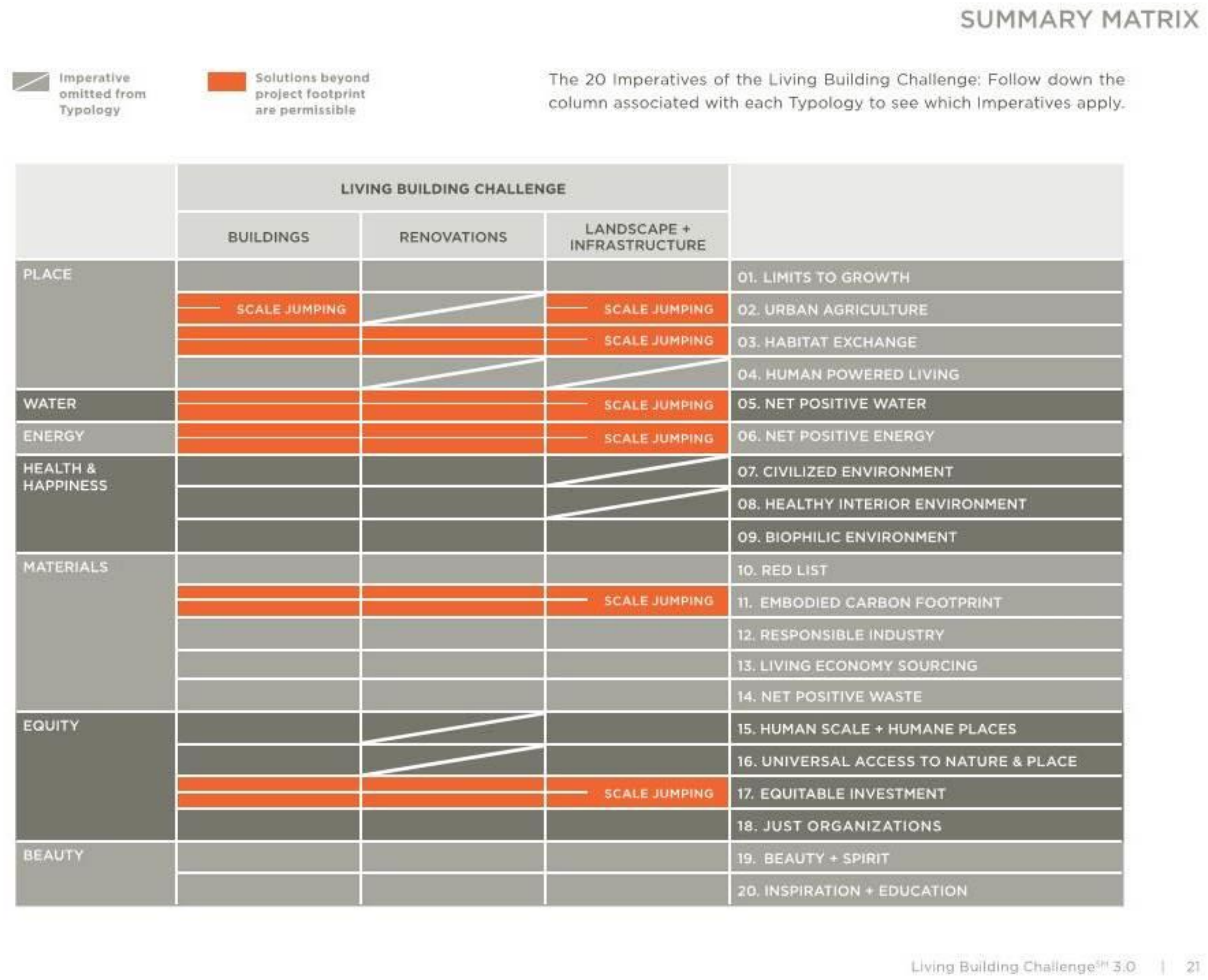
10 Appendix

1. Living Building Challenge:

1.1 LBC Driver



1.2 LBC Summary Matrix



SUMMARY MATRIX

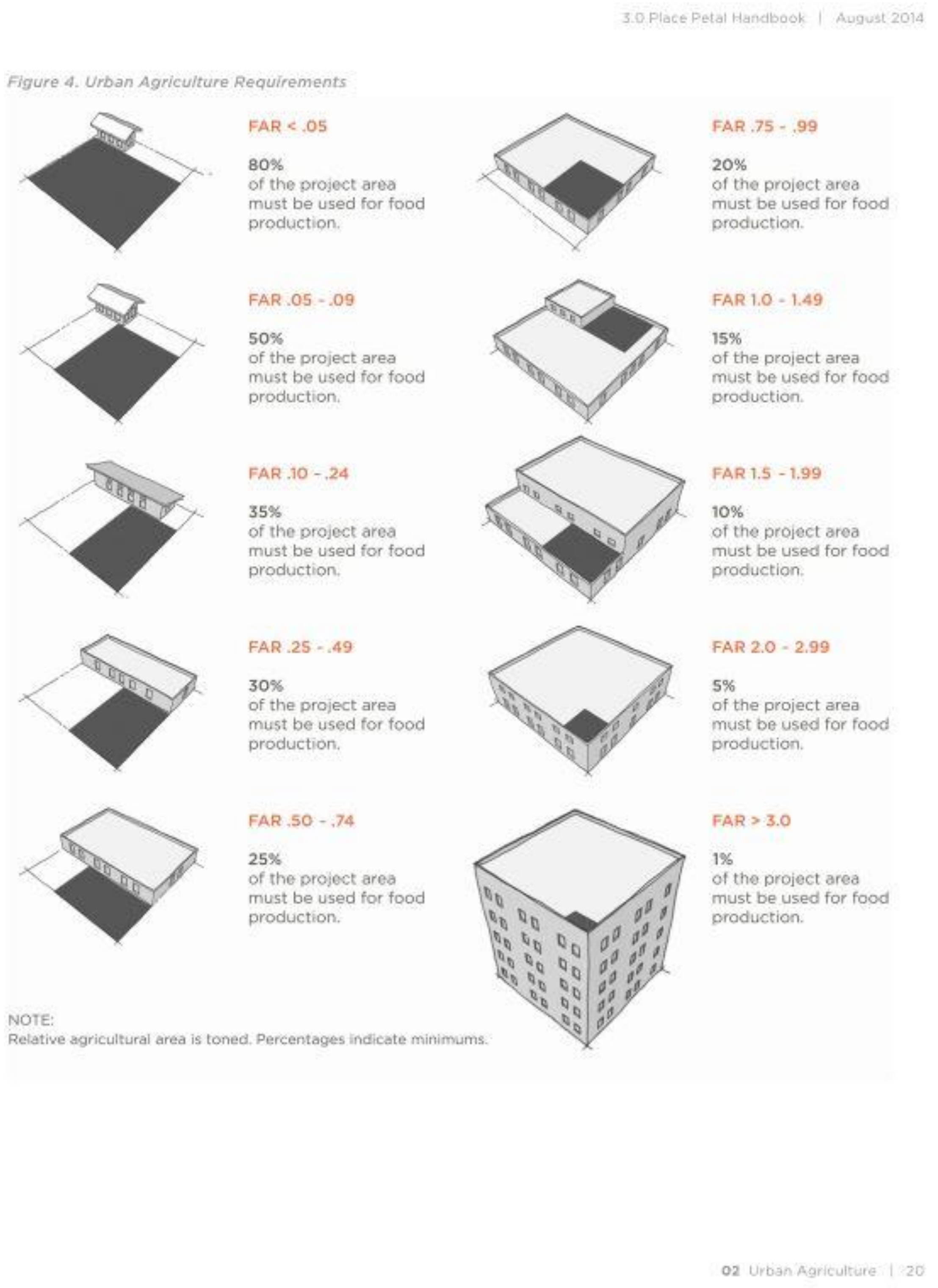
Imperative omitted from Typology

Solutions beyond project footprint are permissible

The 20 Imperatives of the Living Building Challenge: Follow down the column associated with each Typology to see which Imperatives apply.

	LIVING BUILDING CHALLENGE			
	BUILDINGS	RENOVATIONS	LANDSCAPE + INFRASTRUCTURE	
PLACE				01. LIMITS TO GROWTH
	SCALE JUMPING		SCALE JUMPING	02. URBAN AGRICULTURE
			SCALE JUMPING	03. HABITAT EXCHANGE
				04. HUMAN POWERED LIVING
WATER			SCALE JUMPING	05. NET POSITIVE WATER
ENERGY			SCALE JUMPING	06. NET POSITIVE ENERGY
HEALTH & HAPPINESS				07. CIVILIZED ENVIRONMENT
				08. HEALTHY INTERIOR ENVIRONMENT
				09. BIOPHILIC ENVIRONMENT
MATERIALS				10. RED LIST
			SCALE JUMPING	11. EMBODIED CARBON FOOTPRINT
				12. RESPONSIBLE INDUSTRY
				13. LIVING ECONOMY SOURCING
				14. NET POSITIVE WASTE
EQUITY				15. HUMAN SCALE + HUMANE PLACES
				16. UNIVERSAL ACCESS TO NATURE & PLACE
			SCALE JUMPING	17. EQUITABLE INVESTMENT
				18. JUST ORGANIZATIONS
BEAUTY				19. BEAUTY + SPIRIT
				20. INSPIRATION + EDUCATION

1.3 Horticulture Ratio Table



3.0 Place Petal Handbook | August 2014

Figure 4. Urban Agriculture Requirements

FAR < .05

80%
of the project area must be used for food production.

FAR .05 - .09

50%
of the project area must be used for food production.

FAR .10 - .24

35%
of the project area must be used for food production.

FAR .25 - .49

30%
of the project area must be used for food production.

FAR .50 - .74

25%
of the project area must be used for food production.

FAR .75 - .99

20%
of the project area must be used for food production.

FAR 1.0 - 1.49

15%
of the project area must be used for food production.

FAR 1.5 - 1.99

10%
of the project area must be used for food production.

FAR 2.0 - 2.99

5%
of the project area must be used for food production.

FAR > 3.0

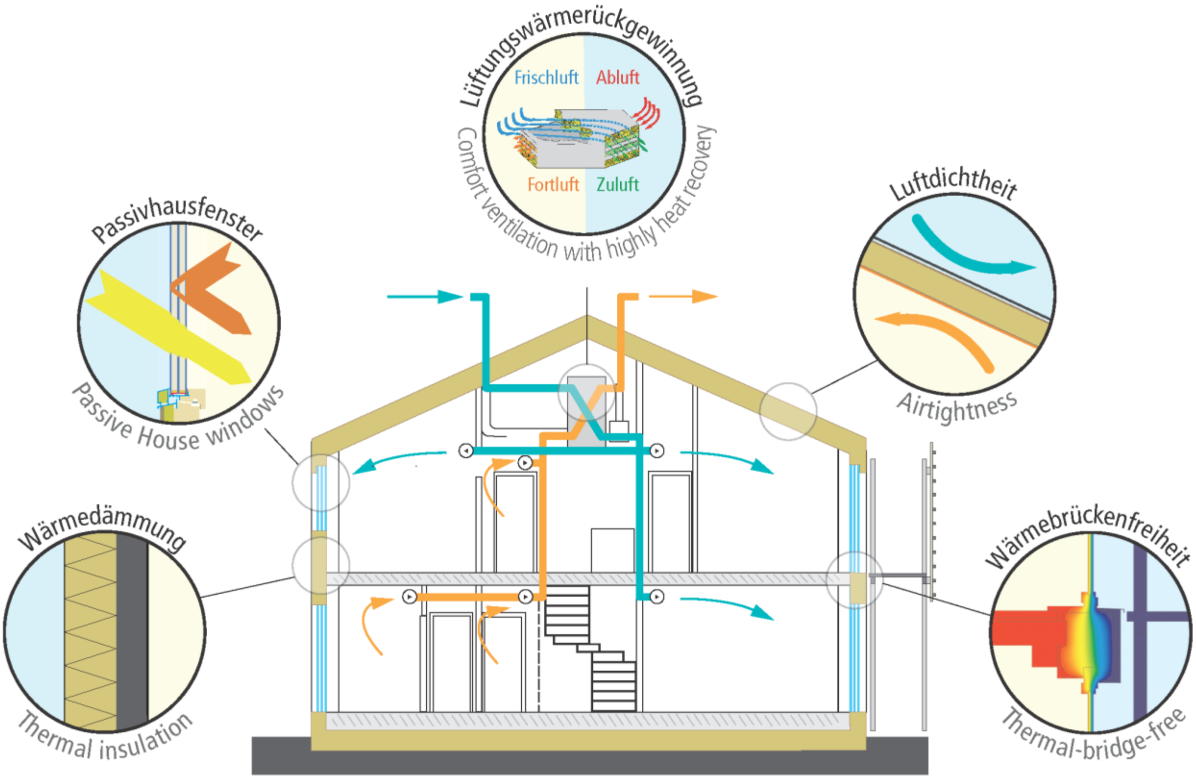
1%
of the project area must be used for food production.

NOTE:
Relative agricultural area is toned. Percentages indicate minimums.

02 Urban Agriculture | 20

2. PassivHaus

2.1 Five Principles of PassivHaus



2.2 PHPP Final Results Summary Sheet

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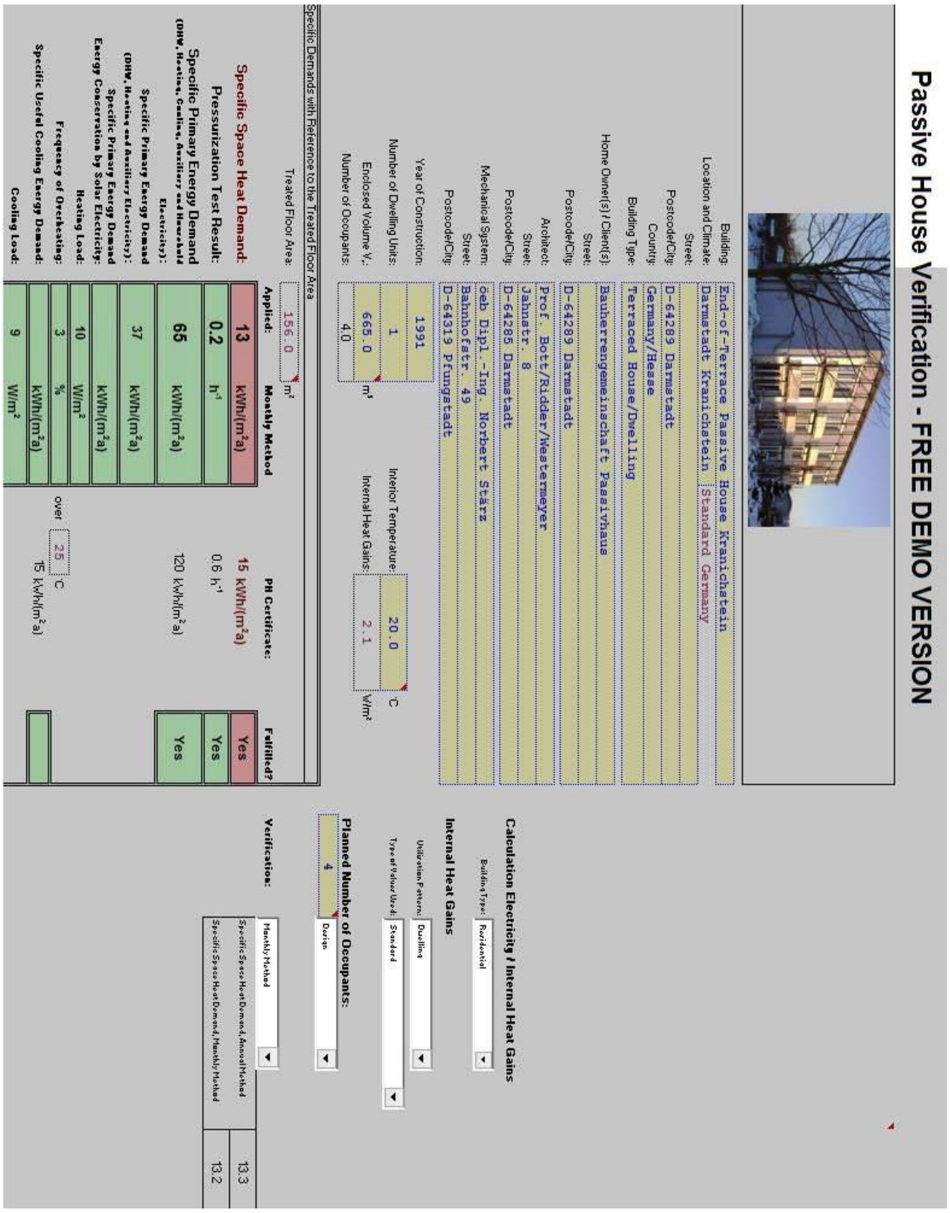
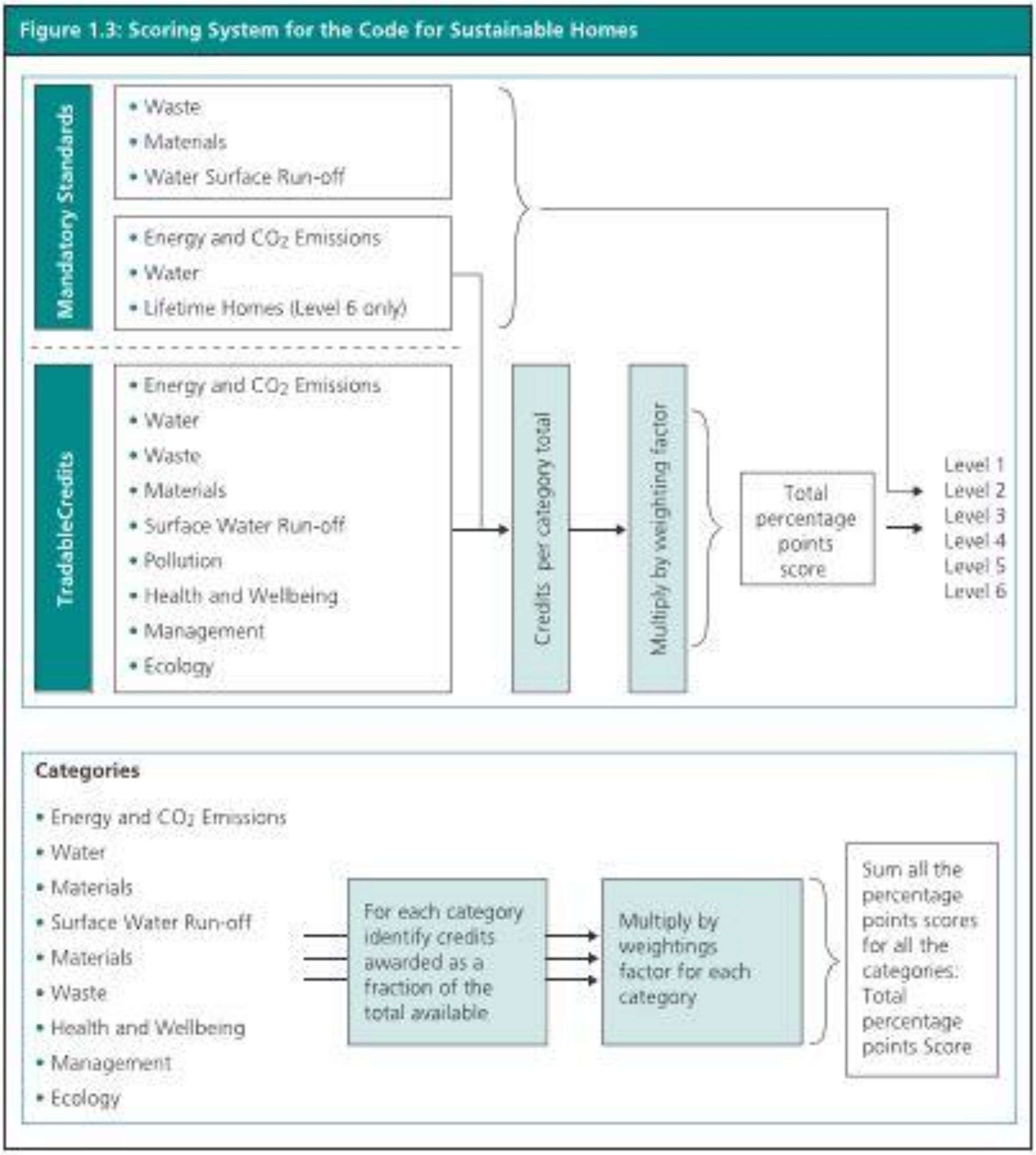


3. BREEAM CfSH

3.1 CfSH assessment paths.

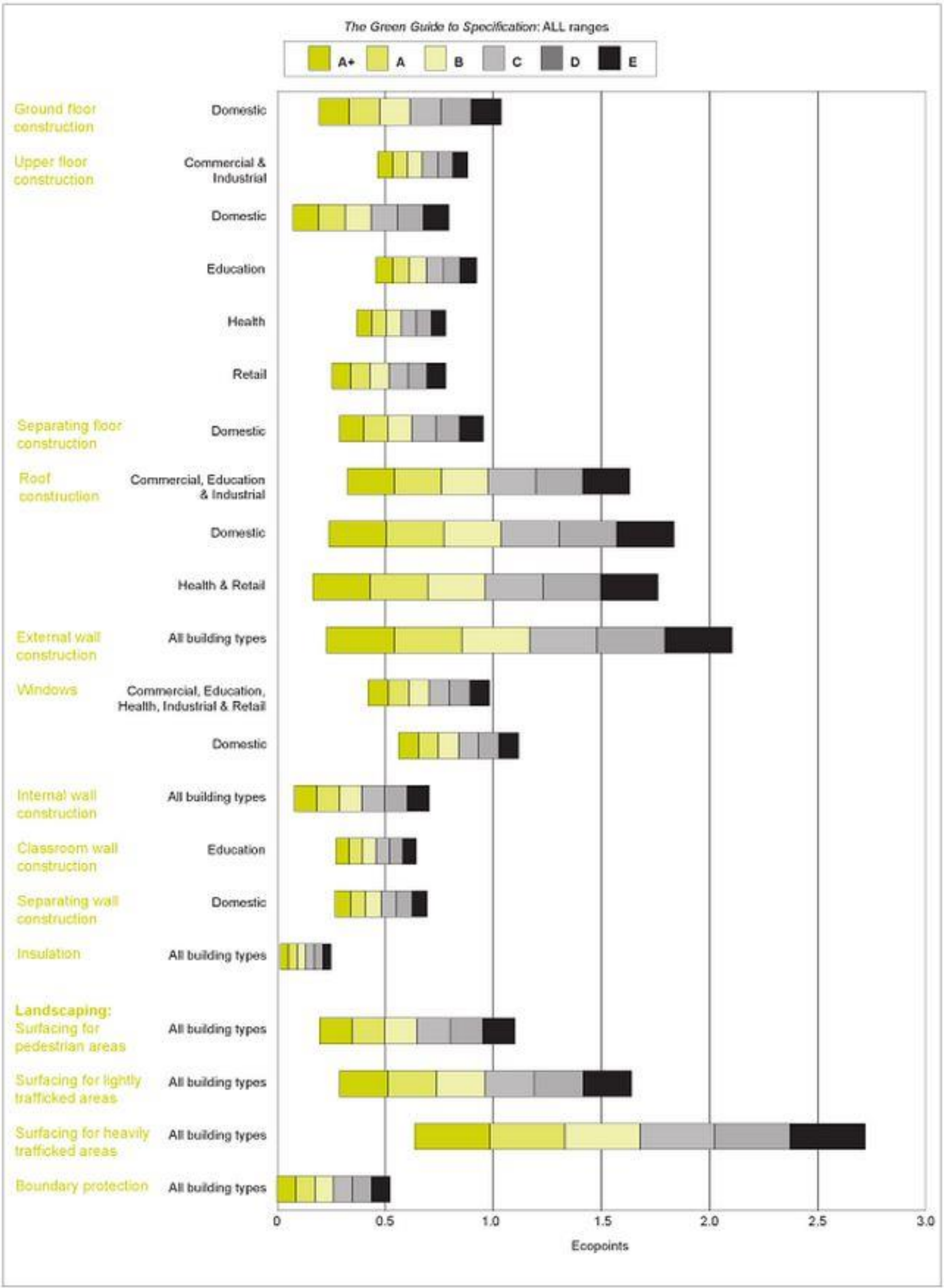


3.2 CfSH Criteria

Table 1.5: Summary of Environmental Impact Categories, Issues, Credits and Weighting		
Code Categories	Available Credits	Category Weighting Factor
Energy and CO_2 Emissions		
Dwelling emission rate	10	
Fabric energy efficiency	9	
Energy display devices	2	
Drying space	1	
Energy labelled white goods	2	
External lighting	2	
Low and zero carbon technologies	2	
Cycle storage	2	
Home office	1	
Category Total	**31**	**36.40**
Water		
Indoor water use	5	
External water use	1	
Category Total	**6**	**9.00**
Materials		
Environmental impact of materials	15	
Responsible sourcing of materials – basic building elements	6	
Responsible sourcing of materials – finishing elements	3	
Category Total	**24**	**7.20**
Surface Water Run-off		
Management of surface water run-off from developments	2	
Flood risk	2	
Category Total	**4**	**2.20**
Waste		
Storage of non-recyclable waste and recyclable household waste	4	
Construction site waste management	3	
Composting	1	
Category Total	**8**	**6.40**
Pollution		
Global warming potential (GWP) of insulants	1	
NOx emissions	3	
Category Total	**4**	**2.80**
Health & Well-being		
Daylighting	3	
Sound insulation	4	
Private space	1	*continued*

Table 1.5: Summary of Environmental Impact Categories, Issues, Credits and Weighting		
Code Categories	Available Credits	Category Weighting Factor
Lifetime Homes	4	
Category Total	**12**	**14.00**
Management		
Home user guide	3	
Considerate Constructors Scheme	2	
Construction site impacts	2	
Security	2	
Category Total	**9**	**10.00**
Ecology		
Ecological value of site	1	
Ecological enhancement	1	
Protection of ecological features	1	
Change in ecological value of site	4	
Building footprint	2	
Category Total	**9**	**12.00**
Total	**107**	**100.00**

3.3 EcoPoint table, upon which ratings are assigned



Mat01 Calculator Interface